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The
Geology and Scenery of the Grampians
and
The Valley of Strathmore

Volume II

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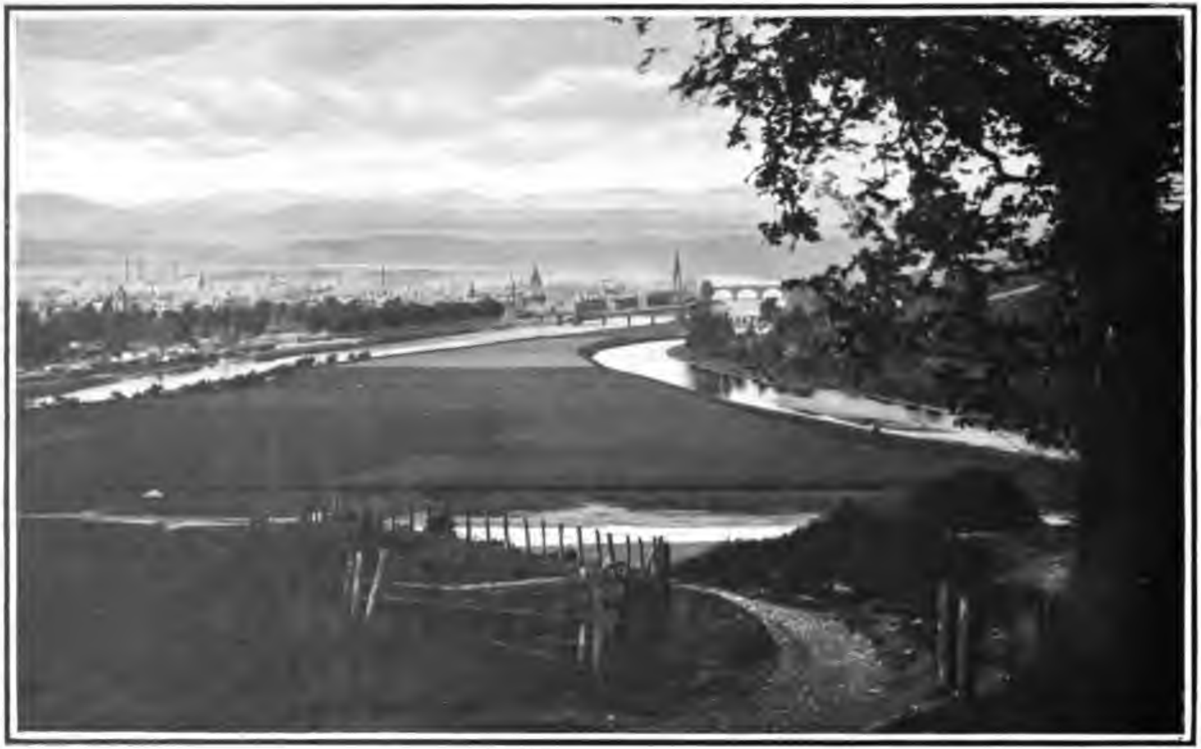

Perth, Strathmore and the Grampians, from Moncreiffe Hill.

Photo. by the late Magnus Jackson.

The Geology and Scenery of the Grampians
and
The Valley of Strathmore

By

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CHAPTER VIII

THE OLD RED SANDSTONE

> "Nature will be reported. All things are engaged in writing their history. The planet, the pebble, goes attended by its shadow. The rolling rock leaves its scratches on the mountain; the river, its channel in the soil; the animal, its bones in the stratum; the fern and leaf, their modest epitaph in the coal. The falling drop makes its sculpture in the sand or stone. Not a foot steps into the snow, or along the ground, but prints, in characters more or less lasting, a map of its march . . . the ground is all memoranda and signatures; and every object covered over with hints, which speak to the intelligent."
>
> EMERSON.

BOTH the Upper and the Lower divisions of the Scottish Old Red Sandstone are represented in our region, the latter occupying nearly the whole of the valley of Strathmore, while the former is confined to a narrow strip in the Carse of Gowrie, and small areas in the neighbourhood of Loch Lomond and the Firth of Clyde.

Along the margin of the Highlands, and abutting against the older crystalline schists, though separated from them by the great boundary fault, we find a massive series of conglomerates thrown down against the schists at high angles (see Fig. 7). These conglomerates, it must be borne in mind, do not represent the actual base of the Lower Old Red Sandstone, but only the local base of a great series of rocks which evidently must have gradually overlapped each other as the land sank beneath the Old Red Sandstone sea. This conglomerate can be traced from Stonehaven in the east, to Arran and Kintyre in the west. Fine exposures may be seen in the beds of the Isla, Ericht, Almond, Turret, Leny, and Avondhu, where they make their passage in debouching upon the plains. In many of these defiles the cliffs are precipitous, as at Craighall on the Ericht, where the river flows through a deep cañon, in which the dark waters are confined by vertical walls of conglomerate. The foot-hills which roll up towards the Grampians, such as Uamh Bheag, Uamh Mhor, the Menteith Hills, and the chain of ridges stretching between Aberfoyle and Balmaha, which include Arndrum, Drum of Clashmore, Gualann Hill, and Conic Hill, consist to a large extent of this basal conglomerate, and owe their prominence to the relatively greater resistance of the conglomerate to the denuding agents (see Figs. 58 and 63, vol. i.).

The conglomerate consists to a large extent of pebbles of quartzite, or of andesite. The former pebbles are evidently derived from the crystalline schists of the Highlands, and are generally of a pure white or flesh colour, being stained on the outside to a deep red colour, and set in a matrix of coarse- or fine-grained felspathic sandstone. The rock which we find in the Highland schists of nearest resemblance to these pebbles is the quartzite of the Central Highlands. As it is now generally believed that this rock is the highest

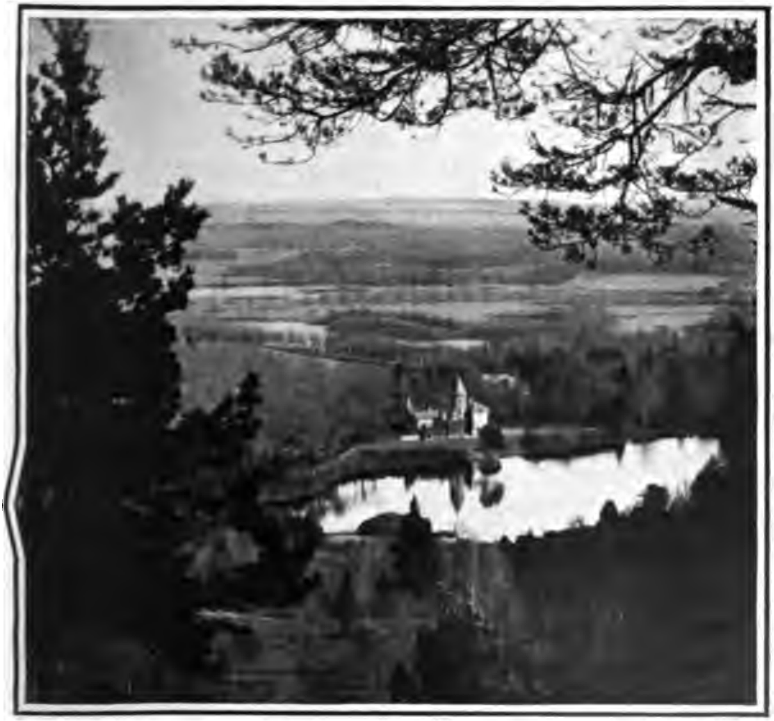

FIG. 1.—Strathmore, from southern slope of Birnam Hill, with Sidlaw Hills in the distance.

Photo. by WM. ELLISON.

member of the Highland series, it seems likely that when the Old Red Sandstone conglomerates were being laid down the underlying limestones and schists had not been exposed. These pebbles may vary from small sizes to huge boulders reaching up to three feet in diameter. Their surfaces are smooth, and they are usually well rounded.

In some cases the pebbles in the conglomerate are principally andesite. They have probably been derived from the contemporaneous lava beds which are found interbedded with the conglomerates and sandstones. Pebbles of other rocks occur, and include schists, quartz-porphyry, felsite, and white quartz.

Many of the pebbles show evidence of having been subjected to enormous crushing, and present marked indentations, from which cracks radiate. These cracks, in some cases, are so numerous as to have completely shattered the pebble, which has been re-cemented with silica, or simply set in a matrix of sand.

Mr. A. L. Du Toit[1] has pointed out that "the planes of crush are generally fairly regular, being nearly vertical and striking N.N.W. and S.S.E., and thus almost at right angles to the plane of the great fault. Often the fractures are arranged just like a series of step faults, the S.W. portion of the pebble being displaced towards the south-east. Large faults cut across the conglomerate from N. to S. or N.N.W. to S.S.E., and are thus approximately parallel to the planes of crush. These transverse faults do not, as a rule, appear to cut across the great fault, and seem to have been produced simultaneously as a result of the great earth movement at the formation of the latter.

---

[1] "The Lower Old Red Sandstone Rocks of the Balmaha-Aberfoyle Region," *Trans. Edin. Geol. Soc.* vol. viii. page 315.

"As the red sandstones and conglomerates sank downwards (to the S.E.), the underlying beds rose (to the N.W.), and the pressure of the abutting mass was sufficient to fracture the conglomerate pebbles, produce transverse faults, and even in places to invert the strata. It may be noted that shattering is more violent at these places where the conglomerates are inverted."

The character of the conglomerate and its position show that it everywhere forms the local base of the Old Red Sandstone. In Glen Turret and Glen Isla it is seen to rest unconformably upon the upturned edges of the Highland grits.

The manner in which the conglomerate has been formed may be explained as follows (see Fig. 3). To the north lay the great continental area, formed of the Highland schists, which was gradually undergoing depression. Along the margin of this sinking land surface thick beds of conglomerate were first laid down. By the continual sinking of the surface these deposits would gradually creep backwards, and when the sea stood at the level *A A'*, the conglomerate would have crept backwards to *A*, and accumulations of grit, sand, and shale would have begun to form further out in the sea. In this manner the conglomerate would always preserve its position at the base of the system, and would in its turn be overlaid by the beds of grit and sand carried further seawards; or, in other words, the coarser material would dip seawards beneath the finer and would appear to be older than it, though as a matter of fact much of the two deposits would be actually contemporaneous.

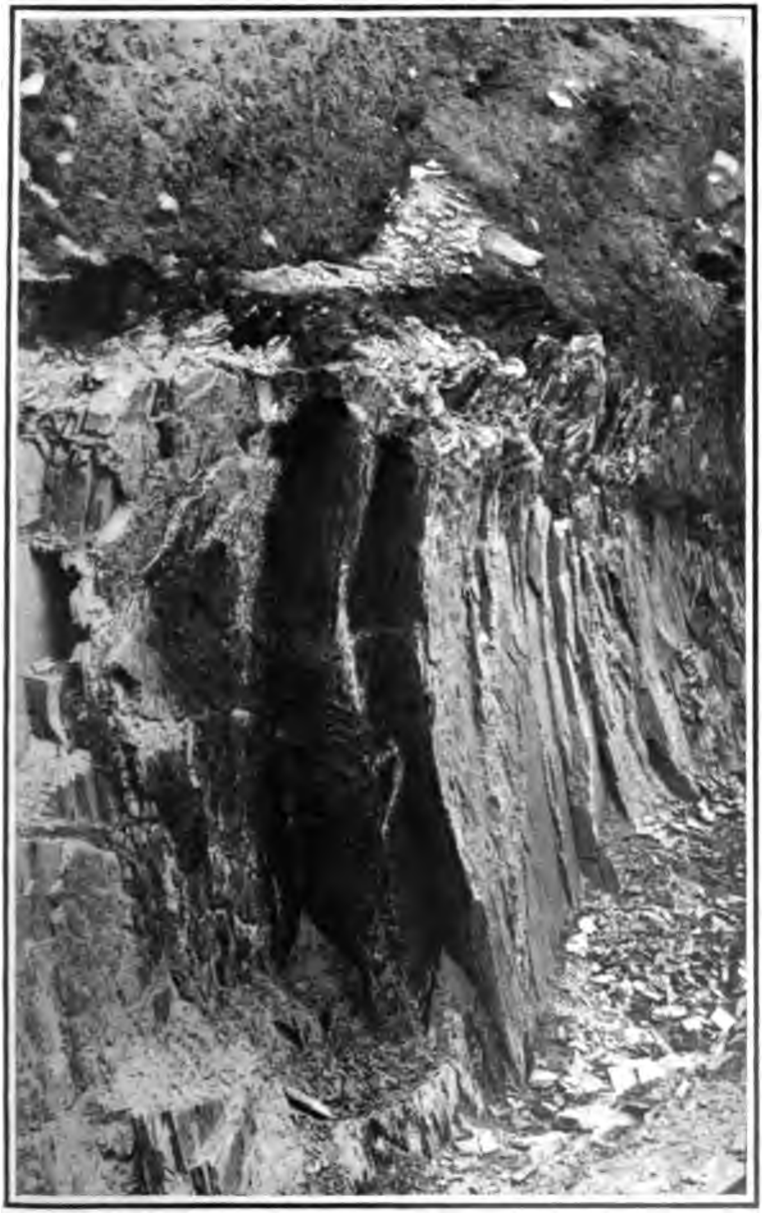

Fig. 2.—Vertical Old Red Sandstone, Crieff and Comrie Railway (with Boulder Clay above).

Photo. by H. Coates.

In a subsequent chapter it will be seen that, during the period when these conglomerates were being formed, the slowly subsiding margin of this great continental area was the site of numerous active volcanic vents, which poured great sheets of lava over the old sea floor, so that thick sheets of lava became interbedded with the conglomerates and sandstones. Fig. 3 also explains how this has taken place, *XX* being a bed of lava, which has been laid down on the underlying conglomerate and sandstones. From the diagram shown in Fig. 3 it will be seen that the lava bed appears to overlie unconformably the sedimentary rocks, though it is actually contemporaneous.

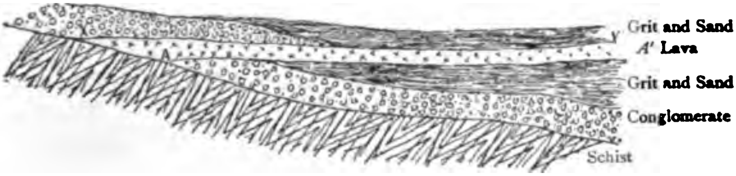

FIG. 3.—Diagrammatic Section showing the manner in which the Fragmental Rocks and Lavas of Old Red Sandstone age were accumulated.

The littoral nature of the conglomerate, as well as its former extensive encroachment upon the Highland area, is well seen in those sections where part of the conglomerate still rests unconformably upon the Highland rocks to the north of the great line of fault; as, for instance, at Craighall near Blairgowrie. On entering the cañon of the Ericht at this place, it will be seen that the conglomerates rest unconformably, and almost horizontally, upon the Highland rocks. Their horizontal position is at first difficult to make out as the bedding of the conglomerate is rather obscure, but the presence of small intercalated beds of sandstone places the matter beyond dispute. Here, then, we stand upon the very base of the system still occupying its normal position, and over the top of which must have been piled thousands of feet of sandstones, grits, conglomerates, and interbedded volcanic rocks. A similar section can be seen in Glen Turret.

Fig. 7 is a section across the area just described, which will help to make the relative positions of these rocks more easily understood. The Highland rocks come to the surface to the north of the section, and are seen to have a general dip towards the north-west. On these rest the basal conglomerates of the Old Red Sandstone. Those to the north of the great line of fault are seen in the section still occupying their normal position upon the Highland rocks. Going south towards Rattray and Blairgowrie, we pass over the great fault, which exposes the basement beds of the conglomerate thrown vertically downwards. Proceeding still further south, we note that the angle of dip gradually decreases, until the conglomerates pass upwards into the sandstones at Rosemount, south of Blairgowrie.

Parka decipiens is said to have been found in thin layers alternating with these basal conglomerates, and it is referred to as occurring in this position in an editorial note appended to a paper by Hugh Mitchell upon these rocks, which was published in the *Quarterly Journal of the Geological Society* for 1861.

As has already been stated, in proceeding towards the south-east we find that the basal conglomerates pass into fine beds of shale and sandstone, which are bent into a synclinal trough. In the upper members of these sandstones there is a well-marked horizon exposed along a line, running from Rosemount near Blairgowrie

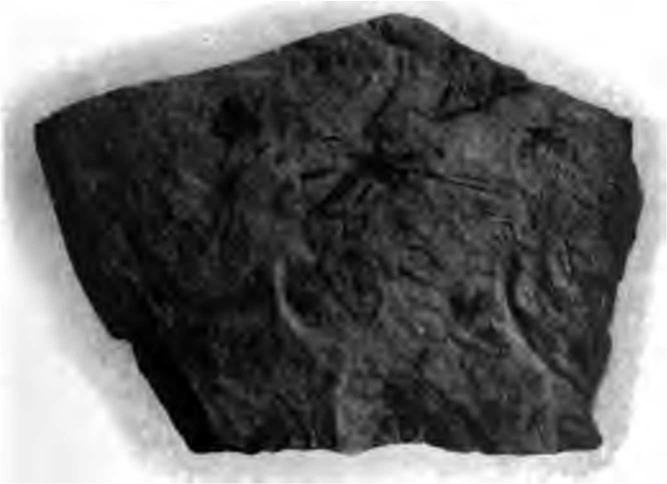

FIG. 4.—*Psilophyton princeps*, Dawson, in Old Red Sandstone, Logiealmond.

Photo. by WM. ELLISON.

by Murthly, Logiealmond, Callander, and Balmaha on the shores of Loch Lomond, where the strata are strongly charged with vegetable matter, principally the decorticated remains of *Psilophyton* and *Arthrostigma*. The geological position of this well-marked zone of plant-remains towards the west, in the counties of Perth, Stirling, and Dumbarton, was indicated in a paper by Messrs. R. L. Jack and R. Etheridge, junr., in 1877. To show the exact geological position of these beds the authors describe a section from the heads of the Kelty and Ruchill Waters through Uamh Mhor and Uamh Bheag to Sheriffmuir. The whole section forms a deep synclinal trough, whose northern limb, seen in the Kelty and Ruchill Waters, consists of massive beds of conglomerate, with shales and interbedded andesites, lying in an almost vertical position against the crystalline rocks of the Highlands. These conglomerates near the summit of the synclinal trough pass upwards into the axial beds of Uamh Mhor—a series of greenish-grey flags and thin-bedded flagstones, plentifully charged with plant-remains, which belong principally to the genera *Psilophyton* and *Arthrostigma*. From this point towards Sheriffmuir the series is a descending one, forming the southern limb of the syncline, and repeating the former beds again in a finer condition, the whole ultimately passing downwards into the volcanic zone of the Ochils. The following table (see p. 8) of these beds is taken from Messrs. Jack and Etheridge's paper:

Professor Harkness states that the grey sandstone passing upwards into red sandstone, and lying above the trappean conglomerate (F in table on following page), is said to have yielded the remains of *Pteraspis*;

CENTRE OF TROUGH, UAMH MHOR, Etc.

A. Fine red conglomerate, with matrix of siliceous sand, enclosing pebbles of white quartz, porphyrite and Ben Ledi grit, the pebbles frequently angular, - - - - - 300 feet

North-west side of Trough, Heads of Kelty and Ruchill Waters.	ft.	*South-east side of Trough, Braes of Doune, Allan Valley, and Sheriffmuir.*	ft.
B. Red pebbly sandstone, matrix mainly siliceous,	500	B. Red pebbly sandstones,	550
C. Greenish grey flags and thin-bedded sandstones, - - -	500	C. Greenish grey flags and thin-bedded sandstones, - - -	750
D. Conglomerate, stones up to 2 inches in diameter mostly of white quartz, some of andesite and various schists, 3300 feet. Red shales, conglomerates, and grey sandstones, 1100 feet. Brown gritty sandstones and brown shales, with calcareous nodules and crustacean-tracks (?) 800 feet, - - -	5200	D. Fine-grained brown sandstones and dull brown shales, 1700 feet. Crumbling felspathic shales, 500 feet. Chocolate coloured sandstones, with calcareous nodules and a few pebbles, 8400 feet,	10,600
		E. Bedded andesites of Wharry Burn, - -	200
F. Very coarse conglomerate, with well-rounded blocks, up to 2 feet in diameter, of andesite and quartzite, chiefly andesite, - -	1500	F. Coarse trappean conglomerate, - -	1100
G. Bedded andesites abutting against fault about a mile south of the section line.		G. Bedded andesites, metaphyres, and ashes of the Ochils, their base masked by a fault.	

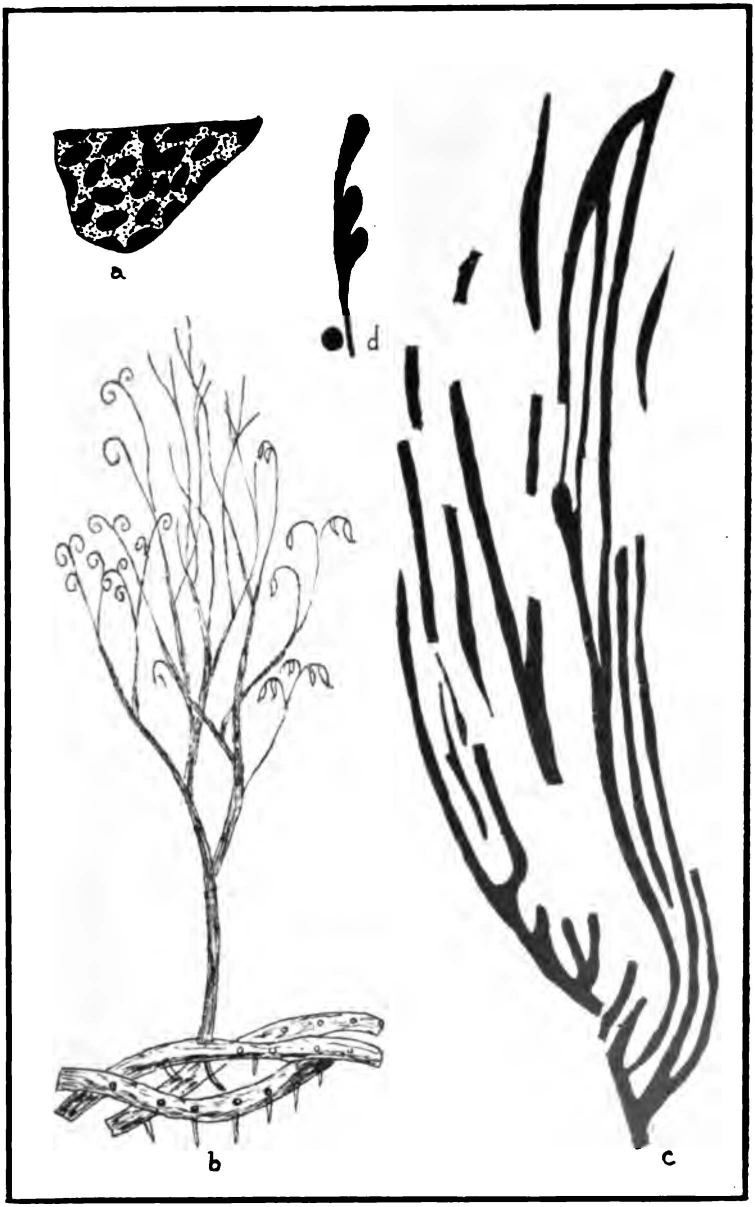

FIG. 5.—Old Red Sandstone Plants (Restored).

a. **Parka decipiens, Part of a Sporocarp.**
b. **Psilophyton princeps, after Sir Wm. Dawson.**
c. **Zosterophyllum Myretonianum, after Prof. D. P. Penhallow.**
d. **Fruiting Spike of Zosterophyllum Myretonianum, after Prof. D. P. Penhallow.**

but no traces of plants, so far as he was aware, have been found in the neighbourhood of Bridge of Allan, nor are there any remains of crustaceans.

Traced south-westwards into the low ground on the west side of the Teith, the flagstones with their plant-remains are exposed at the surface, the higher beds of Uamh Mhor having been entirely stripped away by denudation. Further westwards, towards the shores of Loch Lomond, the area occupied by the Lower Old Red Sandstone becomes narrowed down, owing to the faulting against it of the Upper Old Red Sandstone towards the south. Still, the flagstones with their plant-remains are exposed right on to the shores of Loch Lomond and the Firth of Clyde.

Returning now to the beds in the east of Perthshire, it will be seen that, so far as these upper beds, characterized by *Psilophyton* and *Arthrostigma*, are concerned, they appear to represent a well-marked and distinct horizon near the summit of the Old Red Sandstone series as seen in the county of Perth. On crossing the volcanic zone of the Sidlaws into the Carse of Gowrie, we find a series of sandstones coming up from underneath that range of hills, as at Balruddery. Rolling over, they dip beneath the Ochils on the other side of the Firth of Tay. In these sandstones we find *Parka decipiens*, associated with *Pterygotus*, *Cephalaspis*, etc. Traced north-eastwards into Forfarshire, this same zone appears at Myreton, Carmyllie, Turin Hill, Glamis, and other localities.

In the accompanying section (see Fig. 10) we have shown the relative positions of the *Parka* and *Psilophyton* beds of the Lower Old Red Sandstone of Strathmore, along a line drawn from the base of the Grampians, through Blairgowrie and Rosemount, and thence across the Sidlaws to Balruddery in the Carse of Gowrie, terminating on the other side of the Firth of Tay at Parkhill and the Ochils. Against the crystalline rocks of the Highland border we find the basal conglomerates, with their interbedded volcanic rocks thrown down into an almost vertical position by the boundary fault. Near Blairgowrie these basal conglomerates are cut off by a second fault, with a downthrow to the south which ushers in the higher members of the series in an almost horizontal position, these latter consisting of red and grey sandstones, with local beds of conglomerate, which at Rosemount, about two miles to the south of Blairgowrie, are abundantly charged with plant-remains, referable to *Psilophyton* and *Arthrostigma*. The section is a descending one from this point towards the volcanic zone of the Sidlaws, and after crossing these hills near the exposed base of the volcanic zone into the Carse of Gowrie, we come upon the *Parka* beds at Balruddery, which again roll over to form the Ochils on the south side of the Tay.

From the above section it will be seen that in the *Parka* and *Zosterophyllum* zone of Perthshire, Fifeshire, and Forfarshire, and the *Psilophyton* and *Arthrostigma* zone of Perthshire, Stirlingshire, and Dumbartonshire, there are two distinct and well-marked horizons of plant-remains, of which the former, occurring near the base of the volcanic rocks of Perthshire and Forfarshire, and found associated with characteristic fish and crustacean remains, is undoubtedly the lower of the two. The *Psilophyton* zone occupies a much higher position in the series, being found far above

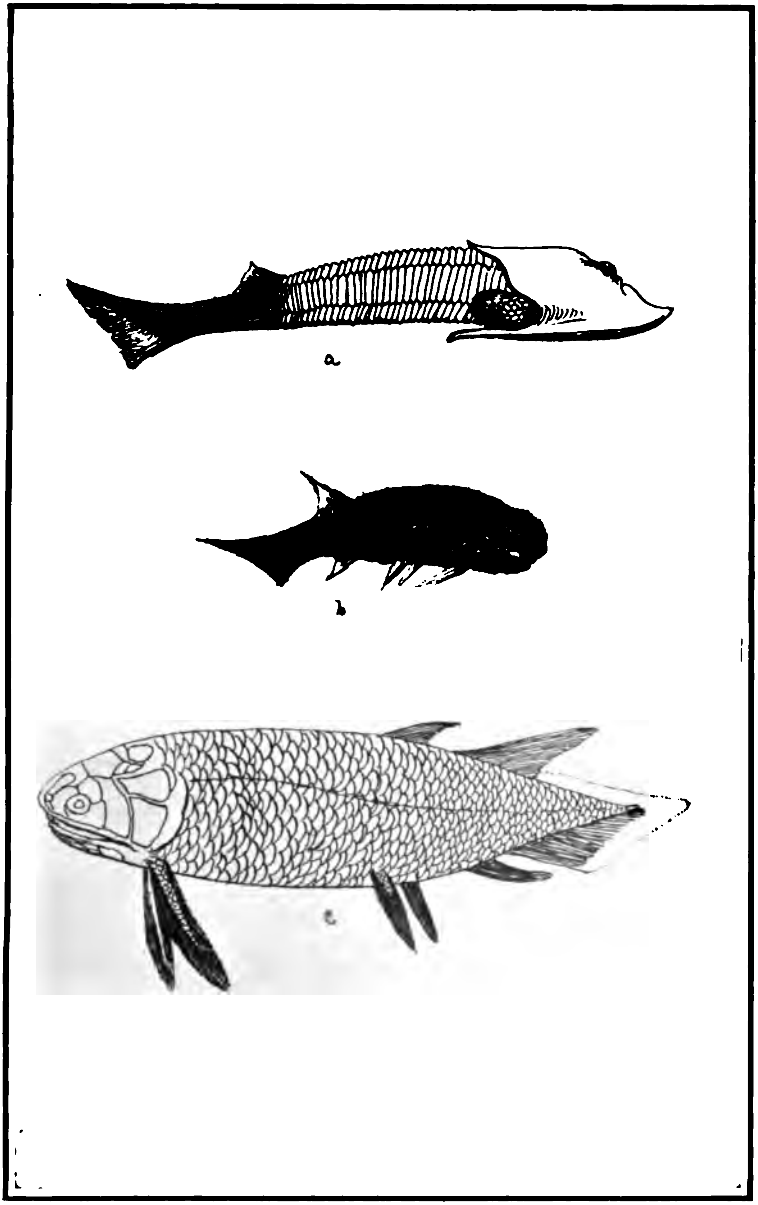

FIG. 6.—Old Red Sandstone Fishes (Restored).

a. **Cephalaspsis Lyelli, after Prof. E. R. Lankester.**
b. **Acanthodes Mitchelli, after Dr. B. N. Peach.**
c. **Holoptychius nobilissimus, after Prof. T. H. Huxley.**

the top of the volcanic zone, and amongst the highest beds exposed in the synclinal trough of Strathmore.

In the plant-remains to which we have referred as occurring in the Lower Old Red Sandstone of Perthshire, we have the oldest terrestrial vegetation of which geologists have anything like a definite knowledge. As a matter of fact, they are in an extremely fragmentary condition; but the Devonian rocks of Gaspé and New Brunswick yielded to the late Sir J. W. Dawson something like 118 species of land plants.

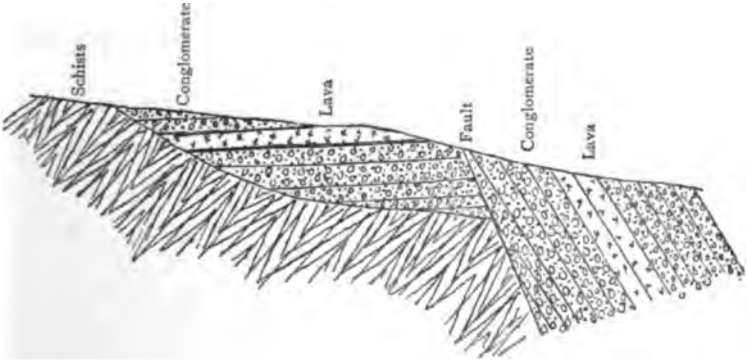

FIG. 7.—Diagrammatic Section showing the Old Red Sandstone resting unconformably on the crystalline schists to the north of the Great Boundary Fault.

In 1889 Mr. James Reid, Blairgowrie, and the author submitted to Sir William Dawson a suite of specimens obtained from the Murthly sandstones, and concerning them he remarks: "*Psilophyton princeps* predominates, as in Gaspé, *Psilophyton robustius* is less abundant, and *Arthrostigma gracile* is represented by some portions of stems. On the whole, the assemblage is exactly that of the lower division of the Gaspé sandstones." A comparison of *Psilophyton princeps* of the Murthly sandstones with *Psilophyton princeps* from

Campbelltown, N. Brunswick, shows that in all points of structure, including the fruit, they are identical.

The genus *Psilophyton* was considered by Dawson to form a connecting link between the Rhizocarps and Lycopods, and he named it *Psilophyton* because of its resemblance to the modern genus *Psilotum*, a parasitic lycopod found in Madagascar, the Moluccas, and the Sandwich Islands. *Psilophyton princeps* occurs abundantly in the sandstones of Gaspé Bay, and with its slender stems and creeping cord-like rhizomes has been described by Dawson as follows:—

"Stems branching dichotomously, and covered with interrupted ridges. Leaves rudimentary or short, rigid and pointed, in barren stems numerous and spirally arranged; in fertile stems and branchlets, sparsely scattered or absent; in decorticated specimens, represented by minute punctate scars, young branches circinate; rhizomata cylindrical, covered with hairs or ramenta, and having circular areoles irregularly disposed, giving origin to slender cylindrical rootlets. Internal structure: an axis of scalariform vessels, surrounded by a cylinder of parenchymatous cells, and by an outer cylinder of elongated woody cells; fructification consisting of naked oval spore cases, borne usually in pairs on slender curved pedicels, either lateral or terminal" (see Figs. 4 and 5).

Arthrostigma, which is found in the same beds with *Psilophyton*, had a more robust habit than the latter plant. Its leaves were narrow and pointed, and borne in a verticillate or spiral manner, its branches bearing terminal spikes of naked sporocarps, having a strong resemblance to those of *Psilophyton*. These two genera of plants are closely related, and unless in a good state

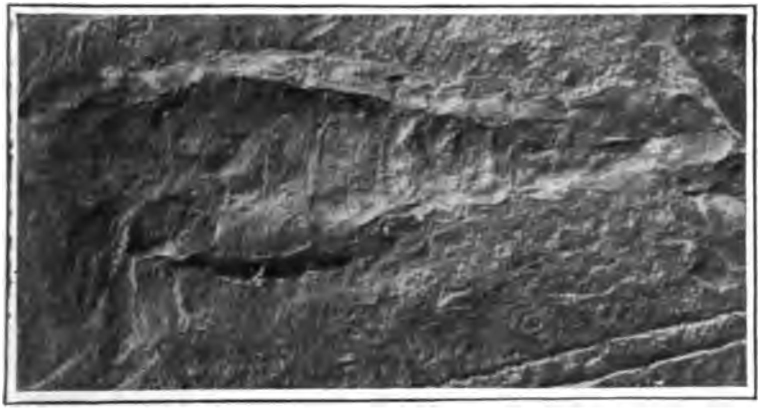

FIG. 8.—*Pterygotus anglicus*, Sandstone Quarry, Carmylie.
(From Specimen in Dundee Museum.)

Photo. by JAS. B. CORR.

of preservation it is difficult to determine the one from the other.

Passing now to a consideration of the plants which are found in the lower zone associated with the volcanic rocks, we find that they belong to two genera, *Zosterophyllum* and *Parka.* Professor Penhallow describes *Zosterophyllum* as "Aquatic plants with creeping stems, from which arise narrow dichotomous branches and narrow linear leaves of the aspect of *Zostera.* Fruit, an ovoid or spherical sporangium (?), produced with short pedicels without subtending bracts from a single axis, the whole forming a loose spike."

The grassy-looking leaves discovered by Dr. Fleming in 1831 indicate *Zosterophyllum.* Nicol, in 1844, appears to have observed the characteristics and zonal value of *Zosterophyllum* and also of *Psilophyton* of the Perthshire sandstones; while Hugh Miller notes a peculiar structure (anastomosis) detected by Dr. Fleming in this genus, which places it in an unique position among the plants of the Old Red Sandstone of Scotland. We have observed this structure in *Zosteropyllum* uniting contiguous leaves together, as Miller remarks, "like the Siamese twins." In speaking of the plants of the Forfarshire flags, Miller says: "I observed in particular one large bunch of ribbon-like leaflets converging into a short stem, so that the whole resembled a scourge of cords." If such a specimen as is shown in Fig. 5 were broken into fragments and scattered over the beds in which *Zosterophyllum* is prevalent, we should find the same exactly represented by the broken fragments of plants met with in these beds. The latter show a simple bifurcation, which is also a characteristic of the parent plant (see Fig. 5).

Parka decipiens, or rather that part of the plant which is now recognized as its sporocarp, and to which the name was originally given by Fleming, consists of oval or circular masses of disc-shaped bodies, in some cases preserved as a black carbonaceous substance, and in others as a mere pseudomorph in iron, from which all traces of its original vegetable structure have been removed. Professor Penhallow recognizes three forms of the sporocarp, one of which he refers to the species, while the other two are recognized as varieties—these being principally founded on differences of form and size, the varieties being named *Parka media* and *Parka minor*. Their dimensions are as follows: *Parka decipiens*, 3.5 × 5.5 cm.; *P. media*, 13 × 20 mm.; *P. minor*, 6 × 16 mm. It may be here noted that the sporocarp of *Parka* shows the internal grooving possessed by the modern Rhizocarpeae. It has been suggested by some that the *Parka* discs or sporangia are of the nature of sporocarps attached to an oval striated leaf-like body. But the discovery by us of a sporocarp from the shales of Myreton, which, splitting in two, showed on one side the usual cluster of discs, and on the other the impressions only, has led us to the conclusion that the sporangia have been enclosed in a sack or covering, of which the grooved portion to which the discs are usually attached forms the one side, while that with the hexagonal or circular impressions only, forms the other. The two taken together complete the indusium. Long linear leaves and rhizomes are usually found in association with *Parka*, but it must be frankly confessed that up to the present time they have never been found in actual organic union. It seems not improbable, however, that in *Parka* we have

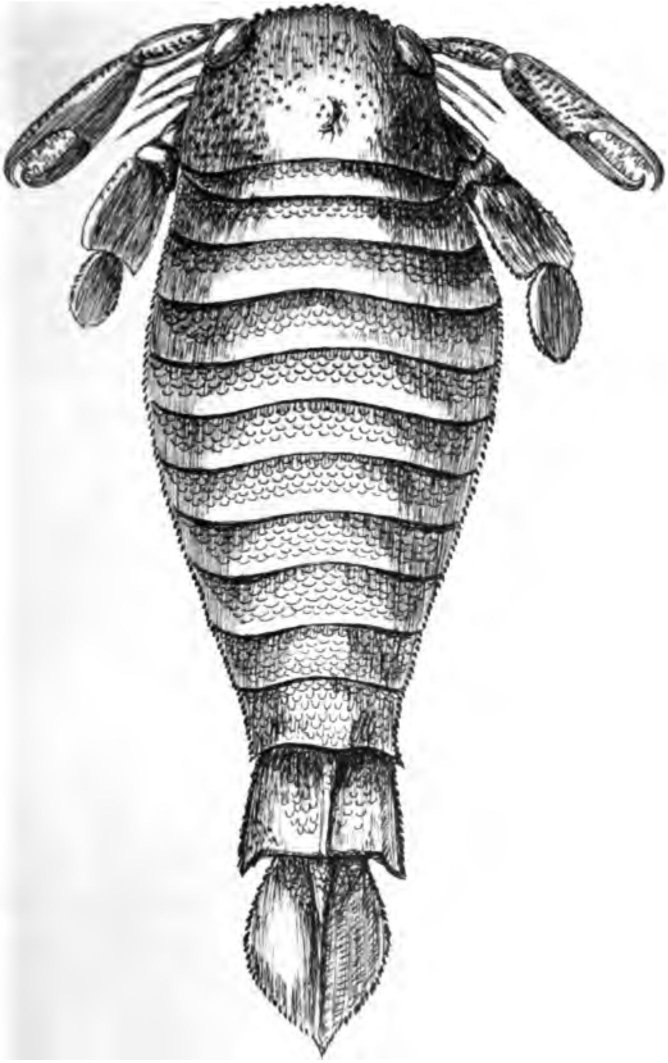

FIG. 9.—*Pterygotus anglicus.* (Restored, after Woodward.)

a somewhat generalized plant, shadowing forth the recent Rhizocarps (*Pilularia*, *Marsilia*, etc.), though of a larger form (see Fig. 5).

With the exception of these plant-remains, and some fragments of fishes and *Pterygotus anglicus*, the Old Red Sandstone of Perthshire is singularly barren of organic remains. The horizon upon which these fishes occur is that of the *Parka* and *Zosterophyllum* zone, and is only seen in Perthshire in the romantic Den of Balruddery, about five miles to the west of Dundee. The Balruddery Burn which flows through the glen, in some parts of its course forms the boundary line between the counties of Perth and Forfar. In the upper part of the glen the burn has cut its way deep into the Old Red Sandstone, which at this point consists of a fine-grained, dark, bituminous sandstone, with a somewhat uniform dip to the south-west. These beds have yielded specimens of the following fishes: *Mesacanthus Mitchelli*, *Climatius reticulatus*, and *Cephalaspis Lyelli*, and of the gigantic crustacean *Pterygotus anglicus*, which is believed to have attained a length of six feet (see Fig. 6).

Further to the east in Forfarshire, as at Turin Hill, near the town of Forfar, and at Farnell, the Old Red Sandstone has yielded the following fishes: *Mesacanthus Mitchelli*, *Ischnacanthus gracilis*, *Climatius scutiger*, *C. uncinatus*, *C. reticulatus*, *Parexus recurvus*, *P. falcatus*, *Euthacanthus Mitchelli*, *E. elegans*, *E. gracilis*, *E. curtus*, *Cephalaspis Pagei*, *C. asper*, *Thelodus Pagei*. These occur with *Pterygotus anglicus*, *Stylonurus ensiformis*, and *Parka decipiens*.

Upon a somewhat lower geological horizon, though still above the main mass of lavas, there has been found at Auchtertyre, near Newtyle, a bed which has yielded *Cephalaspis Lyelli* and *Pteraspis Mitchelli.*

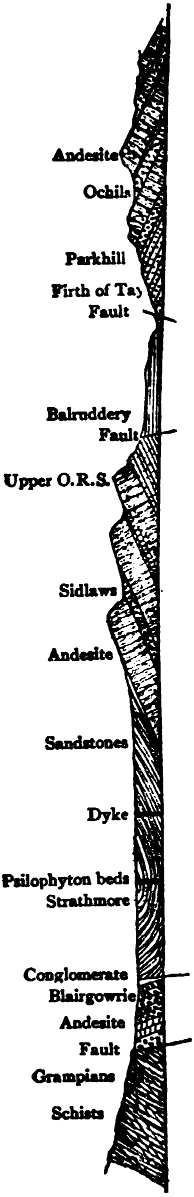

FIG. 10.—Section across Strathmore, from Blairgowrie to the Ochil Hills.

Still lower fossiliferous horizons occur at Carmyllie, which have yielded notable specimens of Eurypterids, *Parka decipiens*, and *Zosterophyllum Myretonianum.* Lowest of all, and apparently about the same geological horizon as the beds exposed in the Den of Balruddery, we have the fossiliferous beds of Myreton, Tealing, and Leoch.

The general biological facies of this fish fauna, according to Dr. Traquair, points to a formation earlier in time than the Old Red Sandstone of Caithness. The occurrence of the genus *Thelodus* in the Old Red Sandstone of Forfarshire helps to link the Perthshire and Forfarshire rocks with the Upper Silurian rocks of Lanarkshire, where *Thelodus* occurs in association with typical Upper Silurian forms, such as *Lingula Lewisii.*

It has been sought to account for the singular barrenness of the Old Red Sandstone rocks of this region by the assumption that they were laid down in lake basins, in which animal life would be extremely rare. In the following chapter we propose to discuss in some detail the physical conditions

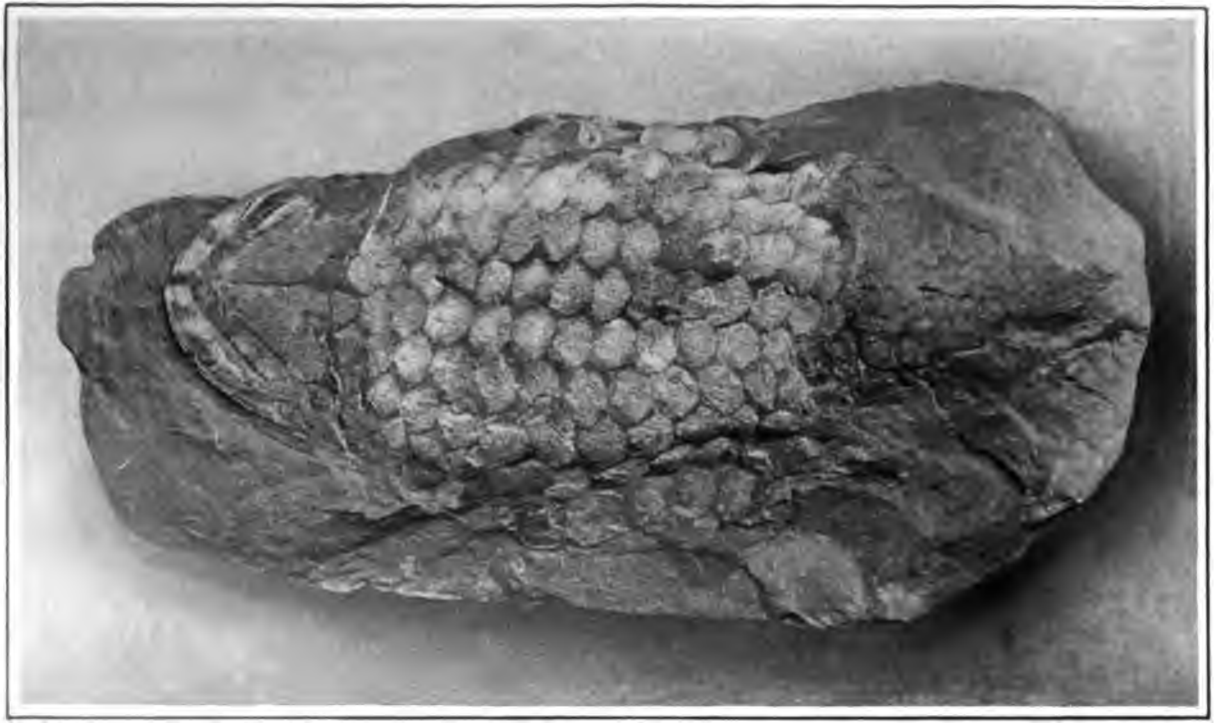

FIG. 11.—*Holoptychius Nobilissimus.* Upper Old Red Sandstone, Clashbonnie.
(From Specimen in the British Museum. Natural History.)

under which these rocks were accumulated. In the meantime we may simply point out that over many square miles, both in the centre and north of Scotland, these sandstones occur, in some cases of enormous thickness, absolutely devoid of any traces of life, except on certain limited horizons where the remains of land plants, fishes, and crustaceans occur. Of late years it has been freely assumed that the evidence is entirely in favour of the view that these sandstones have been accumulated under fresh-water conditions; the presence of land plants, the occurrence of fishes whose modern representatives inhabit lakes and rivers, and the absence of undoubted marine forms, being some of the arguments advanced. But land plants occur in rocks of undoubted marine origin as frequently as they do in the Old Red Sandstone beds; and the value of the evidence derived from the occurrence at the present day of ganoids in fresh-water lakes, and in rivers, is more than counterbalanced by the proof that in Palaeozoic times these fishes were undoubtedly marine, or, to use the significant words of Rütimeyer, that "a flight into fresh-water has been their salvation."

The Upper Old Red Sandstone rocks of Strathmore always rest unconformably upon the Lower Old Red Sandstone, and pass up conformably into the Calciferous Sandstones of the Carboniferous system. In Perthshire they are only developed along the Carse of Gowrie, and have been preserved in rather a remarkable way. They have been carried down into the heart of the Lower Old Red Sandstone volcanic rocks between two powerful faults, and have thereby escaped the general denudation which has swept all traces of them from the great plain of Strathmore (see Fig. 10). In the trough between these faults, there has also been preserved a small patch of Carboniferous rocks, which are exposed at Dron, to the south of Bridge of Earn. These Carboniferous rocks are exceedingly interesting, as they are the only representatives of that great formation which has been found to the north of the Ochil chain, and thus serve to mark the former wide extent of these deposits over the Midland Valley, from which they have been stripped by denudation.

The northern of these two lines of fault has been traced from Craigend round the south front of Moncrieff Hill to Fingask, at which point it crosses the Tay. Passing on it runs along the foot of the Sidlaws by Pitroddie and Kinnaird, and thence eastwards towards Dundee. The southern line of fault runs in a parallel direction from Glenearn, near Pitkeathly, by Dron and Abernethy to Newburgh, where it enters the Firth of Tay below the alluvial deposits by which it is hidden. The effect of this fault has been, as before stated, to bring down into the very heart of the Lower Old Red Sandstone rocks the Upper Old Red Sandstone series, and even in some cases, as at Dron, the basement beds of the Carboniferous series (see Fig. 12). This trough fault has had a most important influence on the topography of the district, for it has carried down the hard volcanic rocks and presented to the surface the softer overlying sandstones of the Upper Old Red and Lower Carboniferous series, which in turn have been worn away by the processes of denudation. They thus give rise to the present valley of the Tay below Perth.

The existence of these trough faults, and their structural importance, were first pointed out by James

Powrie in a valuable paper contributed to the Geological Society of Edinburgh in 1868,[1] in which he seeks to show that the operations of the denuding agents are in many instances influenced to a considerable extent by earth movements. We call attention to the paper because we believe that the merit of working out the structure of the Tay valley below Perth belongs to Powrie. In the *Scenery of Scotland*[2] Sir A. Geikie had advanced the view that the valley of the Tay was eroded before the Upper Old Red Sandstone had been deposited in it: whereas Powrie maintained that the upheaval of the Sidlaw and Ochil ranges had probably not taken place till after Carboniferous times; that the Upper Old Red Sandstone had been faulted downwards in the volcanic zone; and that the faulting had been the principal factor in determining the position of the Tay valley between Perth and Dundee. We shall discuss the subject, however, in more detail in a future chapter dealing with the geology and scenery of the region.

The Upper Old Red Sandstone, as seen at Inchture, Clashbennie, Bridge of Earn, and other localities lying within the trough fault, consists for the most part of dull-looking, reddish, or greyish-yellow sandstones, which are often marked with circular spots of a greyish-yellow colour, and which vary in size from half an inch up to six or seven inches in diameter. In some cases these spots have been found to enclose a fragment of an organism. Many of the beds also show beautiful examples of sun-cracks and ripple-markings, which attest the littoral nature of these deposits. In the neighbourhood of Clashbennie their dip is found to be a little to the east of due south. Clashbennie has been rendered famous to geologists, as it was here that the original type specimen of *Holoptychius nobilissimus*, a characteristic Upper Old Red Sandstone fish (see Fig. 11), was found. It is now preserved in the South Kensington Natural History Museum. Associated with *Holoptychius* there have also been found at Clashbennie the scales and plates of another fish, *Phyllolepis concentrica*.

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[1] "On the Working together of Igneous and Denuding Agencies in the Formation of Scenery," *Trans. Edin. Geol. Soc.* vol. i. p. 185, 1868.

[2] *Scenery of Scotland*, 1st edition, p. 286, 1865.

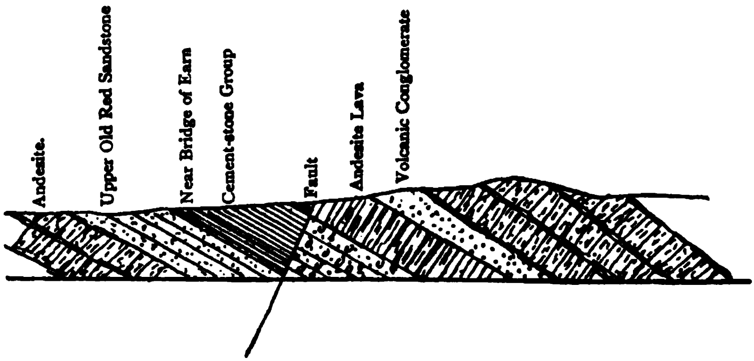

FIG. 12.—Section across the Lower Carboniferous Rocks at Dron, near Bridge of Earn.

At Quarry Hall, near Bridge of Earn, the Upper Old Red Sandstone was observed to lie unconformably upon the lavas of the Lower Old Red Sandstone. Unfortunately, this exposure has now been covered up, but numerous blocks of dull purplish-red sandstone, which enclose fragments of the andesite lava, may be seen in the neighbourhood.

At East Dron, about a mile and a half to the south of Bridge of Earn, the Upper Old Red Sandstone

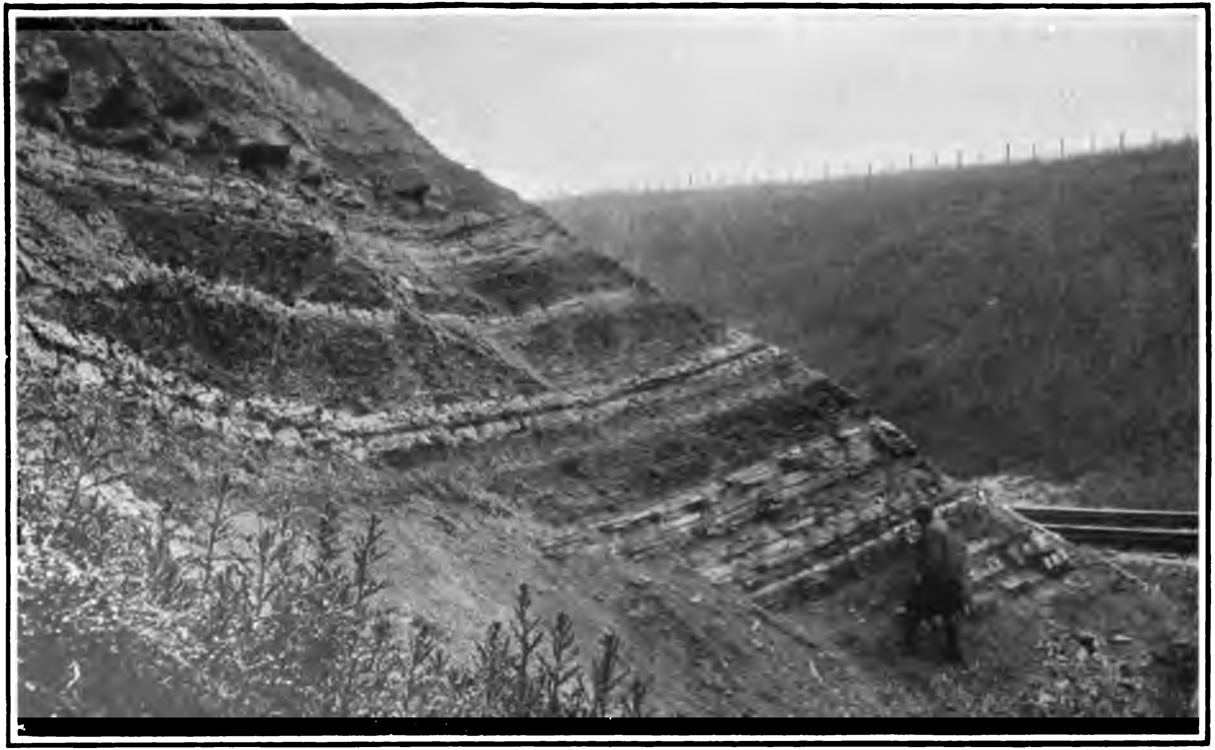

FIG. 13.—Lower Carboniferous Beds, Dron, near Bridge of Earn.

Photo. by WM. ELLISON.

passes upwards into the basement beds of the Carboniferous system, and consists of red and greenish shales and marls, white and red sandstones, and conglomerates. They evidently belong to the Cement-stone group, which attains such an extensive development beneath the volcanic zone of the Campsie and Kilpatrick Hills, and which is so well exposed at the Spout of Ballagan and Auchenreoch Glen. The beds at Dron have yielded the remains of Carboniferous plants, shells, and fish (see Fig. 12).

The amount of displacement caused by these trough faults cannot be exactly determined, as we have no reliable data as to the extent of the unconformability between the Lower and Upper Old Red Sandstone. There cannot, however, be any doubt that it must have been several thousand feet. And, as the Upper Old Red Sandstone and Carboniferous strata must have occupied a position above the volcanic rocks of the Ochils, and as the Cement-stone group was most likely covered by the later Carboniferous rocks, we can safely conclude that at one time the Ochils and Sidlaws were buried beneath a thick mantle of younger Palaeozoic rocks which have now been swept away by denudation.

CHAPTER IX

THE PHYSICAL CONDITIONS UNDER WHICH THE OLD RED SANDSTONE WAS DEPOSITED

But I should turn mine ears and hear
The moanings of the homeless sea,
  The sound of streams that swift or slow
  Draw down Æonian hills, and sow
The dust of continents to be.

TENNYSON.

BEFORE passing on to discuss the physical, petrological, and palaeontological evidence bearing upon the origin of the Old Red Sandstone, it would be useful to give here a brief recapitulation of the physical conditions of our country prior to the deposition of these later Palaeozoic deposits. It is generally believed that in early Palaeozoic time the main land mass must have lain somewhat to the north-west of the present continent of Europe, and may have partly existed in what is now the deep basin of the Atlantic. The old Archaean gneiss of the islands and northern Highlands seems to represent part of the primitive core round which the later Palaeozoic rocks were accumulated. We do not now propose to discuss the origin of those early Palaeozoic rocks, but to us the massive red sandstones and conglomerates of Loch Torridon only

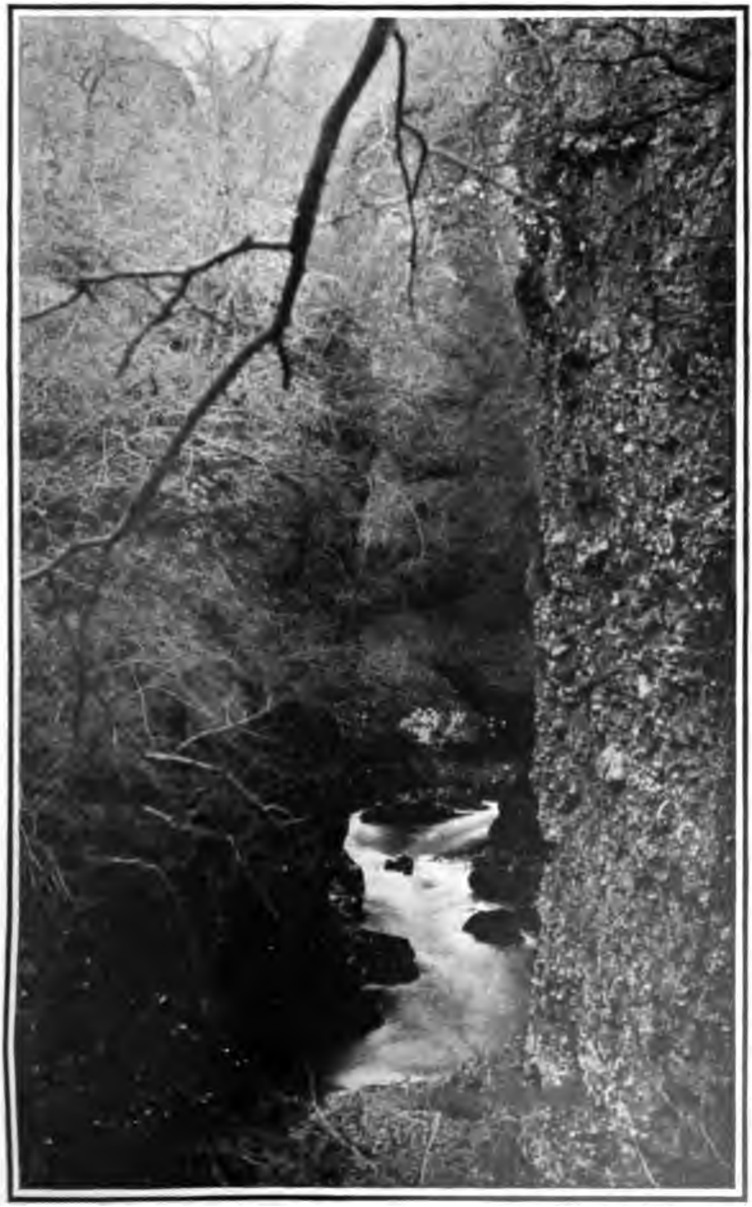

FIG. 14.—Lower Old Red Sandstone Conglomerate, on the Ericht, **near Craighall,** Blairgowrie.

Photo. by JAS. RICHARDSON.

shadow forth the same physical processes that were at work in the still later Old Red Sandstone age; lying as they do upon the older Archaean rocks, they are the undoubted littoral accumulations along that ancient coast-line, which are invariably seen to accompany a great period of mountain-building, indicating that a rapid process of subaerial denudation must have been at work in the higher regions, the detritus being swept out through the old river courses and subsequently rearranged along the shore-line by the action of the sea. But to this point we propose to return later on. Immediately to the east of those Torridon sandstones and conglomerates, but separated by powerful thrust faults, we find a great series of metamorphosed rocks, forming the main mass of the Scottish Highlands. In the intervening period which elapsed between the deposition of the lowest member of this group and the highest, the whole series of beds was subjected to a great process of upheaval into a mountain chain of elevation. The great mass of this mountain chain, then, must have lain to the north-west of the present Old Red Sandstone area; and we now proceed to show how, after this long period of upheaval, the mountain mass once more began to sink below the level of the sea, and how the waters of the Old Red Sandstone sea gradually levelled it down to the very core.

Let us pass on to notice some of the physical and stratigraphical aspects of the matter. A consideration of the deposits lying immediately upon the metamorphosed rocks which then formed land, leads us to the conclusion that the whole of this continental area must have been in a gradually sinking condition, and that these huge masses of conglomerate, lying at the local base of the Lower Old Red Sandstone wherever the latter is exposed, point unmistakably to the existence of a great series of unstable sea margins, slowly creeping inward upon the main mass of the gradually sinking land. Along the flanks of the Grampians, and now exposed by a powerful fault, we have a great mass of conglomerate, consisting in some cases of boulders nearly six feet long. The conglomerates range across the country from shore to shore; in some cases north of the line of fault we have these conglomerates still occupying their normal position upon the older schists and grits. If the effect of this fault were undone, and these conglomerates were raised to their original position, they would stretch far over the Grampians, along with the higher deposits of sandstones and their fish remains, which now occupy the central valley of Strathmore. The following diagram, drawn to scale, will show this very clearly (see Fig. 16).

The dark part of the section to the north represents the present elevation of the Highlands above the level of the sea drawn to scale, and culminating in Ben Muich Dhui. To the south of the line of fault are shown the massive beds of Old Red Sandstone conglomerates, etc., dipping at high angles to the south-east, and estimated to be about 20,000 feet in thickness, fully four times the present height of Ben Muich Dhui. At the point *A*, immediately to the north of the line of fault, and resting directly upon the old crystalline schists, are often to be found patches of the basal conglomerate of the Lower Old Red Sandstone still occupying its normal and unaltered position: so that if the effect of the great fault were undone, and

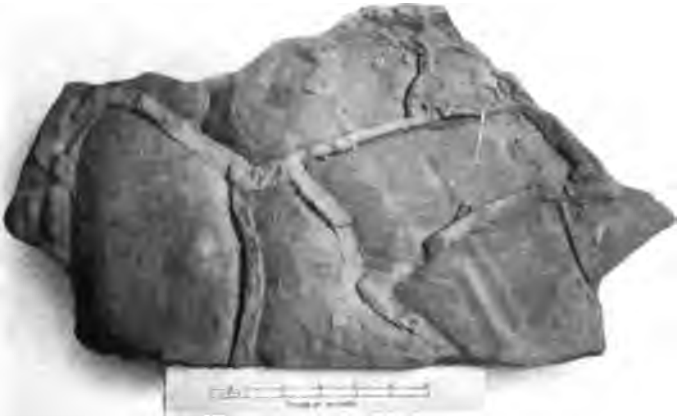

FIG. 15.—Sun Cracks in the Lower Old Red Sandstone, Logiealmond.

Photo. by WM. ELLISON.

the whole Old Red Sandstone deposits of Strathmore were upraised to their original position, they would overlook the Highland area to an altitude of more than four times its present highest elevation. Of course we do not mean to say that the Highlands have not suffered any denudation since their mantle of Old Red Sandstone rocks was swept away; but what we do mean to maintain is, that supposing the original mountain chain was as high as the present Alps, still these deposits would have swept over it and united the so-called basins of Lake Orcadie and Lake Caledonia. It is impossible to consider seriously the idea that these basins continued to sink *pari passu* with the deposition of their sediments, the narrowness of the ridge separating them entirely precluding the idea, as the bottom beds would be contorted and folded long before the upper beds of the 20,000 feet of sediment were laid down, whereas we do not find a break in the whole series. On the other hand, it would be nigh impossible to exclude the sea from such a sinking area, and for such a length of time. As if to make their original connection quite sure, outliers and fragments are found on the ridge of crystalline rocks, as at Mealfourvonie

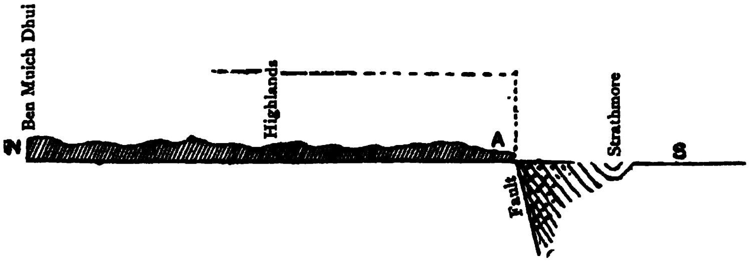

FIG. 16.—Diagram Section to show the former extension of the Old Red Sandstone over the Highlands.

to the height of 2284 feet, at Tomintoul, and at Rhynie, right on what must have been the centre of the ridge, had separate basins existed, and where there should have been no deposits. Sir A. Geikie[1] accounts for these by supposing them to have been little isolated basins or arms of the lake running into the separating ridge. But this method of argument is exceedingly specious. It would be much more scientific to consider them as outliers of a great deposit that once covered the Highlands, the remainder of which has now been entirely swept away. Again, in Caithness there are many evidences of the denudation of these basal conglomerates from the surface of the old marine plain upon which they were laid down. On Ben Griam the conglomerates cap the top of a mountain 1936 feet above the sea-level; the conglomerate is exceedingly coarse, sometimes the boulders being two feet in length, the total depth of the sandstone formation on this mountain being estimated by Sir A. Geikie at 1000 feet. Another instance is mentioned by Sir A. Geikie[2] in his Memoir on the Old Red Sandstone of Western Europe, where he says he was informed by Mr. Crawford, Tongue House, that on Ben Armine, a mountain rising to a height of 2338 feet, in the heart of eastern Sutherlandshire, conglomerate occurs. There can be little doubt, as the older geologists believed, that the whole of the Highlands of Scotland were at one time covered with a vast thickness of Old Red Sandstone rocks. The period at which the denuding process which formed these Old Red Sandstone rocks began, would of course be subsequent to

[1] *Scenery of Scotland*, 2nd edition, p. 141.

[2] *Trans. Roy. Soc. of Edinburgh*, vol. xxviii. p. 383.

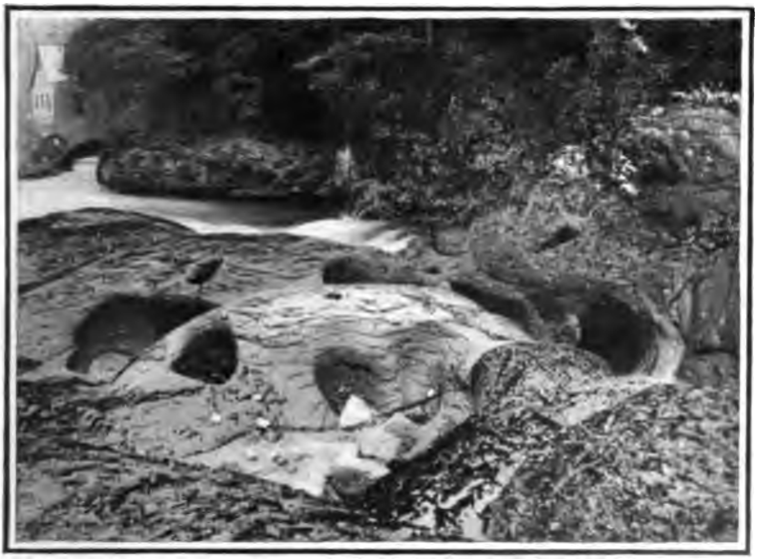

FIG. 17.—Lower Old Red Sandstone, with Pot Holes, on the River Ericht, near Blairgowrie.

Photo. by JAS. RICHARDSON.

the metamorphism of the crystalline schists themselves, and was probably contemporaneous with the deposition of the higher members of the Upper Silurian age. That this is so is evident from the manner in which the latter pass up conformably into the lower Old Red Sandstone at Lesmahagow, in Lanarkshire. They there contain an abundant supply of Upper Silurian forms, and undoubtedly go to prove that the work of carving out the great chain of upheaved and metamorphosed older Palaeozoic rocks had already commenced along the skirts of the chain. These deposits seem to us to represent somewhat of a deep-water aspect, and it is very probable that the corresponding littoral deposits of conglomerate may lie somewhere beneath the later Carboniferous formations of the Midland Valley. Along the northern margin of the Midland Valley no evidence has yet been found of the Upper Silurian rocks as seen at Lesmahagow, though some of the basal conglomerates may be upon the same horizon, representing the littoral deposits to the north of the Lesmahagow beds on the south. The occurrence of *Pachytheca* in the sandstones at Murthly, seems to indicate that the old Upper Silurian flora had not yet passed away when these rocks were deposited. The discrepancies between the fossils of Lanarkshire and Forfarshire on the one hand, and between the fossils of Forfarshire and Caithness on the other, are so great that we are driven to the conclusion that the three must represent different horizons of a gradually ascending and overlapping series of beds, each marked by a distinctive fauna and flora, and also by strong lithological differences. The following section will better explain our position (Fig. 18).

During Upper Silurian times, the mountain chain was depressed as far as the point marked *A*, these deposits being now shown passing up into the Old Red Sandstone. By the time the chain had been depressed as far as *B*, the Silurian types had passed away, and were now represented by those organisms found in Forfarshire. Finally, the whole mountain mass was so far depressed as to cover the entire Highland area as seen at *C*, when the Forfarshire types had, in their turn, been superseded by those of Caithness. Subsequent to this, the Midland Valley was depressed between the powerful trough faults; the upturned edges at the south showing Silurian types, and to the north, those of Old Red Sandstone times. Had these rocks been deposited in a basin, we should have expected the strata to be more or less homologous on each side of the basin; but this, as we have shown, is decidedly not the case. Jukes-Browne,[1] in his *Building of the British Isles*, makes some very pertinent remarks upon this subject. He says: "From the proofs which have been adduced of the original wide extension of the Old Red Sandstone, it might be thought that the three principal basins could hardly have been separate lakes, but must

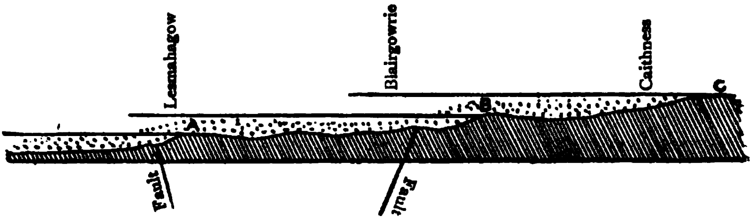

FIG. 18.—Diagram to show the manner in which the Scottish Old Red Sandstone has been deposited.

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[1] *Building of the British Isles*, p. 61.

have been inlets proceeding from one large inland sea, the greater part of which lay to the east of Scotland." And, indeed, so far as the stratigraphical evidence goes, this would be the most natural conclusion, for the lithological differences between the strata of the several basins are hardly greater than the differences which exist between the Lanark and Forfar types in the Caledonian basin. The palaeontological differences are, however, very much greater; the piscine fauna of the Forfar and Caithness flags being so distinct, that Sir R. Murchison thought they could not be of the same age, and was led to suggest that the Caithness flags formed a middle group distinct from the Lower Old Red, and of younger date than the flags of Arbroath, in Forfarshire. Further on, he says, there is less evidence for regarding the Cheviot basin as distinct from the Caledonian, as no fish have yet been found in the Cheviot district, and we do not know how far the Lower Old Red originally stretched over the Southern Uplands. We have lately been examining the Lorne basin, and nothing will persuade us that it is other than an outlier removed and preserved from the main mass by the effects of some powerful faults. The presence of such extremely large boulders in its massive conglomerates as that seen in the base of the well-known Dog-stone of Dunolly, entirely precludes the possibility of its being formed in a basin only a few miles wide. The stratigraphical evidence from the volcanic phenomena, we also consider, is strongly against the basin origin of these deposits; for instance, a great mass of volcanic rock forming the Sidlaw and Ochil hills is found interbedded with the sediments of the so-called Lake Caledonia basin, at a height of several thousand feet above the base. Now in the whole of the 16,000 feet of Lake Orcadie this volcanic zone is entirely absent, which, we think, points to the fact that these two basins could not have been contemporaneous; for, had that been so, further evidence of this extensive volcanic activity would have been found in Lake Orcadie, considering the narrowness of the ridge that must have separated the two basins.

The process which metamorphosed and plicated the crystalline schists of the Highlands into a true mountain chain, also upheaved them above the general level of the surrounding sea, when they immediately became the prey of the subaerial denuding agents. Then followed a long and intense period of subaerial and marine denudation, commencing in early Silurian times, and lasting all through the long period of the Lower Old Red Sandstone age. It is evident, from a consideration of these Upper Silurian and Lower Old Red Sandstone deposits, that the old mountain chain was gradually sinking along its flanks, and that the sea, slowly advancing upon this sinking land, laid down these deposits, the first and lowest of which we see in the south of Lanarkshire, and the highest and latest in the topmost beds of the Lower Old Red Sandstone as developed in Caithness. It has generally been believed that all the stratigraphical evidence has been in favour of these separate areas of Old Red Sandstone being also separate basins of deposit; but it will be found that however difficult it may be to explain the exact conditions under which these rocks were accumulated, one thing is certainly evident, and that is, that they were not deposited in isolated basins as maintained by Godwin-Austen, Ramsay, and Geikie.

In Sir Archibald Geikie's *Scenery of Scotland*[1] will be found the most detailed treatment that has yet been given to the working out of the physical evolution of our country, the opinions contained in it being those generally accepted and followed by present-day geologists. Referring to the second edition of that work at p. 137, on the chapter dealing with the tableland of the Highlands, he says: "The long flat surfaces of the Highland ridges cut across the edges of the vertical strata mark, I believe, fragments of a former base level of erosion; in other words, they represent the general submarine level to which the Highland region was reduced after protracted exposure to subaerial and marine denudation. . . . And in this rolling plain we should find a restoration of the bottom of a very ancient sea." He further goes on to say: "The first fact which a study of the topographical features and geological structure of the Highlands establishes is, that the ancient land, formed after the stupendous movements that gave the rocks of the region their present character, was worn down by prolonged denudation. Its mountains were levelled, its valleys were planed down, and finally the region was reduced to a base level of erosion beneath the waves either of a group of great lakes or of the sea."

Let us now examine more carefully, and in greater detail, these statements of Sir Archibald Geikie. The latter part of the paragraph just quoted seems to us to indicate in a few words the rather indefinite idea which he gives in his *Scenery of Scotland* of one of the most important points in the physical evolution of our country. He says that the old crystalline rocks of the Scottish Highlands were reduced to a base level of erosion beneath the waves either of a group of great lakes or of the sea. Sometimes, in the course of this chapter, we would think it was the sea. For instance, as in the sentence just quoted, where he says: "In this rolling plain we should find a restoration of the bottom of a very ancient sea." Again, a few sentences previous to this, he says they represent the general submarine level to which the Highland region was reduced. Once more, as before quoted, he does not seem to be very sure as to whether this base level of erosion was the action of a group of lakes, or of the sea. In trying to fix the geological date of this vast denudation, he says that it must have been accomplished between the time of the Lower Silurian and that of the Lower Old Red Sandstone system. Probably the waste began in the Lower Silurian period, and continued during the vast series of ages that extended into the period of the Old Red Sandstone. Here, again, we would think he was referring this immense denudation to the group of fresh-water lakes, as he refers to it as being continued during the vast series of ages that extended into the period of the Old Red Sandstone.

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[1] *Scenery of Scotland*, 1st and 2nd editions, under the heading "Tableland of the Highlands."

We must confess to having great difficulty in following Sir A. Geikie's description of the succession of physical events that took place immediately after the plication and upheaval of the old mountain chain. But we think the following may be taken as a fair representation of his meaning: That after the plication and metamorphism of the crystalline rocks of the Highlands, the whole mass was reduced to a plain of

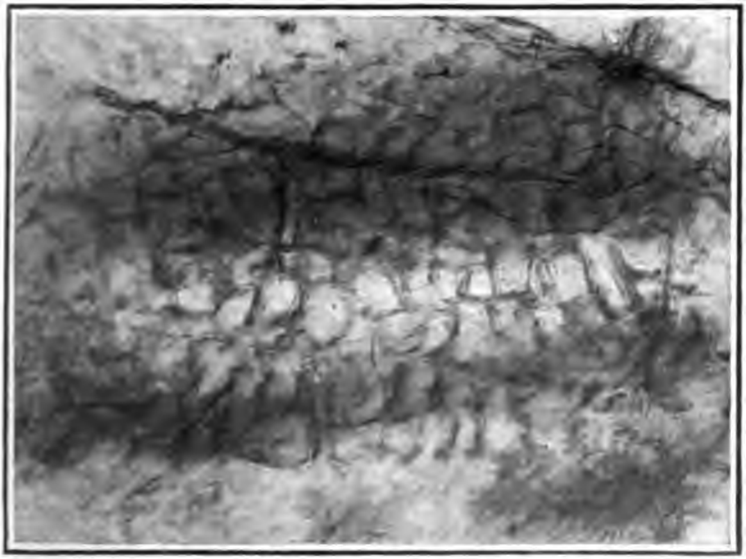

FIG. 19.—Sun Cracks and Ripple Markings in the Old Red Sandstone, Laggan Quarry, near Crieff.

Photo. by D. M. GALL, B.Sc.

marine denudation by a sea which has left no traces whatever of this immense denudation in the shape of later deposits; and that afterwards this plain of marine denudation was depressed into regions occupied by fresh-water lakes, into which, as the land sank and the margins of the lakes crept inward upon it, were thrown down the deposits now known as the Lower Old Red Sandstone formation. Generally speaking, the whole tenor of the chapter dealing with the tableland of the Highlands seems to indicate that an extensive marine denudation reduced the massive mountain chain of the Highlands to a base-level of erosion, altogether distinct from the later denudation which threw down the massive conglomerates of the Old Red Sandstone with its 20,000 feet of sandstones and shales.

Now we would maintain that this first marine denudation, which levelled down the old mountain chain, was identical with the deposition of the Upper Silurian and Lower Old Red Sandstone rocks; pointing out that, though Sir Archibald Geikie believes that it was the sea which levelled down the old continent, he cannot show us anywhere the remains of this immense denudation, all the later rocks lying upon it being of Old Red Sandstone age, and, according to his view, having a fresh-water origin. Further, we cannot see how, if the whole land surface were reduced to a level plain first by marine denudation, this plain could be now preserved, seeing that subsequently it was ridged up into isolated basins to hold the fresh-water lakes. It is evident, then, that Ramsay, Geikie, and their followers distinctly recognize two periods of denudation after the plication of the crystalline schists into a mountain chain. The first period of denudation cut down this mountain chain to a dead level of erosion, called by them a plain of marine denudation, which was produced by the action of the sea. This period, however, strange to say, seems to have left no traces behind in the shape of marine deposits, for immediately resting upon this ancient plain, wherever it has been preserved, we have the great basal conglomerates of the Old Red Sandstone, which they all agree in referring to a lake or fresh-water origin.

The amount of misconception that exists as to the succession of events after the plication of the Highland schists is indeed wonderful, and may be traced principally to these theories of the physical and geological development of our country as given in Sir A. Geikie's *Scenery of Scotland.* The following is a very fair example. Professor Davis,[1] of Harvard University, in a paper on the rivers of England contributed to the Royal Geographical Society's Magazine, speaking of the plain of marine denudation as described in the afore-mentioned work, says: "Although perhaps not absolutely stated, it is clearly implied that it was Devonian erosion by which the once low and comparatively even surface of the now uplifted and dissected Highlands was produced; it is plainly manifest that Devonian erosion consumed a great volume of the contorted and overthrust rocks of the Highlands: witness the great volume of the Devonian strata lying unconformably upon the Highland rocks, and the identity of the Devonian conglomerate pebbles with the rocks of the older terranes. It may indeed be well argued from Sir A. Geikie's essay on the Old

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[1] *Geographical Society's Journal* for 1895.

Red Sandstone of Western Europe that a vast denudation was accomplished in earlier times than the Old Red Sandstone period, and that by the close of that period the Highland region must have been truly a diminished lowland, a peneplain of small area and moderate relief." This is a very good example of the misconception, and general indefiniteness, which accompany Sir A. Geikie's description of the physical events following the plication of the crystalline rocks of the Highlands; for Professor Davis speaks of Devonian seas having cut down the Highlands to their base-level, and of conglomerates belonging to that age resting upon them, and then of Old Red Sandstone conglomerates, as if there were two distinct sets of rocks in Scotland, one marine and Devonian, the other fresh-water and of Old Red Sandstone age. Of course the error is quite excusable in one who has never studied the rocks of our country, but only read of them in the *Scenery of Scotland.*

We have already noticed the strong similarity between the conglomerates of the Torridon Sandstones and those of the later Old Red Sandstone rocks. Both of them show evidence of glaciation, and it has recently occurred to us that this may be connected in some way with the fact that they are both seen to follow a great process of mountain-building. This fact, we think, would indicate that the great mountain mass had been upheaved above the limit of the snow-line, the consequent descent of glaciers having played an important part in contributing their morainic débris to the formation of these massive conglomerates now lying at the base of both the Pre-Cambrian and the Old Red Sandstone deposits, the origin of which is not, we believe, to be sought for in any lacustrine deposit, as has been maintained by Ramsay, Geikie, and Hull. They are rather types of a great series of shore deposits gradually accumulating along the margin of a slowly sinking continental area (see Figs. 16 and 18), which in its upper regions is rapidly undergoing subaerial denudation. This type of deposit is not uncommon all through the geological scale, and to it we believe the Old Red Sandstone conglomerates of Scotland belong. Professor Bonney[1] makes interesting remarks upon this point in his address to the British Association in 1886. He there says that "Pebbles indicate the action of the waves of the sea or of strong currents, marine or fluviatile." Further he continues: "The waves of lakes have also some rounding effect, but this, except in the case of very large lakes such as Lake Superior, is not important, and such cases are, of course, not of common occurrence."

As we have already pointed out, the massive conglomerates of such a small basin as we are led to believe Lake Lorne must have been, and, what is still further in evidence, the much smaller basins that are alleged to have existed on the separating ridge between Lake Caledonia and Lake Orcadie, entirely preclude, even from a petrological point of view alone, the possibility of their being other than outliers of the main mass. The whole petrological aspect of the Old Red Sandstone rocks, as seen in Scotland, is, of course, highly indicative of their littoral origin; the entire absence of any of the deeper oceanic types of sedimentation, such as limestone, also confirming this view. The rocks as seen in Caithness, Forfarshire,

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[1] *British Assoc. Report*, 1886.

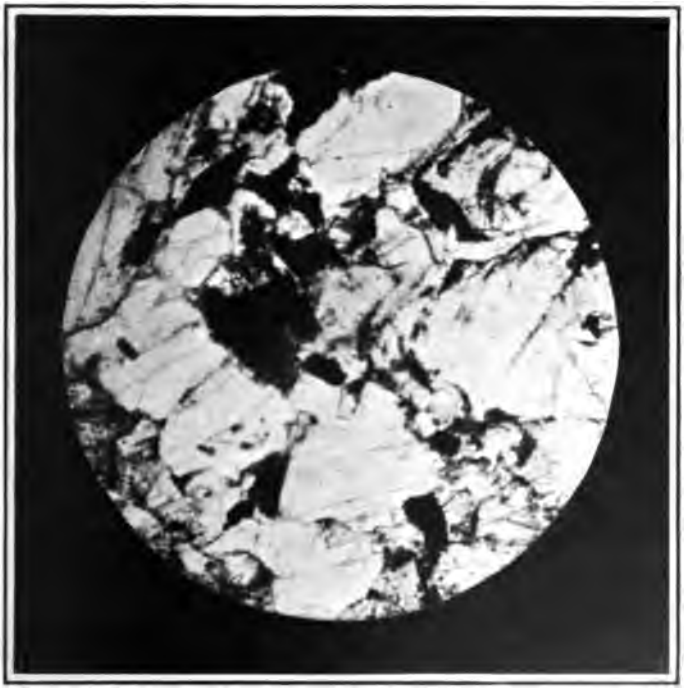

Fig. 20.—Granitite. Garabal Hill. (Magnified 25 dias. Crossed Nicols.)

Photo. by Jas. B. Corr.

and Perthshire, and generally in the valley of Strathmore, mainly consist of great beds of grey and red sandstone, with occasionally local deposits of conglomerate, the great feature of the whole being their characteristic red colour. Now we think that this red colour, due to the presence of the red oxide of iron in the rocks, cannot be fairly claimed as an argument for the fresh-water origin of these deposits. Professor Gosselet has shown that in the Devonian basin of Dinan the same beds are in one part red, and barren of organic remains; and in another part of the same area are of the usual colour, and full of marine fossils. With Sir Charles Lyell[1] we ask the question, Why should shells and corals be generally wanting in all sedimentary rocks, the colour of which is determined by the red oxide of iron? and we believe that the answer cannot lie in the assertion that they are all fresh-water deposits, seeing that even in such undoubted marine deposits as the Devonian, Carboniferous, and Permian formations it is common, in the ordinary beds, to find corals and shells, while those coloured with peroxide of iron are entirely barren of organic remains. The solution of the problem rather lies in the fact that the presence of peroxide of iron in these rocks is inimical to the preservation of fossils with a calcareous test, and more especially so in the case of sandstones, which, even when composed of pure silica, are well known to be a bad medium for the preservation of molluscan and other similar organic remains.

Sir R. I. Murchison held that the three groups of the Devonian system represent the Lower, Middle, and Upper divisions of the Old Red Sandstone, the

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[1] *Elements of Geology*, 3rd edition, p. 435.

Lower occurring in Forfarshire and the Middle in Caithness.[1]

Sir A. Geikie, however, dissents from this view, and classes the deposits of Midland Scotland and those of the Caithness area into Lower and Upper Old Red Sandstone.[2] From a stratigraphical point of view this classification apparently leaves little to be desired, but an examination of the palaeontological evidence shows that the facts are not strictly in accordance therewith. He dwells strongly upon the occurrence, in the northern and the southern areas, of *Pterygotus*, *Acanthodes*, *Psilophyton*, and, we might add, a recent find of *Cephalaspis* in the Caithness flags,[3] as proofs of contemporaneity. But the scanty remains of *Pterygotus* and *Cephalaspis* met with in the Caithness flags apparently indicate a life verging upon extinction and a period later in time. The evidence derived from the occurrence of acanthodian fishes in the northern and southern areas becomes of minor importance when we know that the acanthodians range upwards through the Old Red and Carboniferous formations into the Permian. Again, we find that *Psilophyton* occurs in the Lower, Middle, and Upper Sandstones of Gaspé and New Brunswick.[4]

On the other hand, Dr. Woodward refers to the discovery of some 300 pteraspidian fishes in the Lower Devonian rocks of Cornwall, while *Phyllolepis* and other fish remains occur in the Upper Devonian strata. It is also to be noted that numerous fishes of the

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[1] *Siluria*, 3rd edition, 1859, p. 284.

[2] "The Old Red Sandstone of Western Europe," *Trans. Royal Soc. Edin.* vol. xxviii. 1879, pp. 361-362.

[3] *Annals of Scottish Natural History*, 1893, pp. 206-207.

[4] *Geological History of Plants*, Dawson, 1888, pp. 277-280.

Middle and Upper Devonian system of Russia are specifically identical with those of the Old Red Sandstone of Scotland.[1]

The testimony of plant-remains points in a similar direction. The genus *Psilophyton* first makes its appearance in the upper beds of the Middle or Caledonian series of the Scottish Old Red Sandstone deposits. Its decorticated remains, with occasionally more perfect specimens showing fruit and characteristic circinate vernation, as has already been pointed out, crowd the sandstones stretching from Rosemount, south of Blairgowrie, through Murthly, Logiealmond, Callander, Gartmore, and thence onwards to the shores of the Firth of Clyde. Formerly *Psilophyton* was supposed to occur upon a much lower horizon, namely, in the fossiliferous beds which underlie the volcanic zone of the Sidlaws and Ochils, and which, appearing at Balruddery, stretch north-eastward into Forfarshire. But *Psilophyton* has never been definitely ascertained to occur upon this horizon, the broken remains of *Zosterophyllum* being often erroneously referred to this plant. *Psilophyton* also occurs in the Orcadian series, specimens of the plant having been found in the John o' Groats beds, and in the flagstones around Thurso, as at Holburn Head, Hill of Forss, and Castletown, also at Kilmister, Wick. It seems, therefore, to range from the upper sandstones in the axial beds of Strathmore, of the Caledonian series, to the highest beds of the Orcadian series, as seen at John o' Groat's House. The genus *Lycopodites* is only known to occur in the upper or Orcadian series, and seems to be confined to the Thurso flagstone group.

[1] *Text Book of Geology*, Sir A. Geikie, 1882, p. 704.

The genus *Zosterophyllum* is first known to appear in the Caledonian group, and in the beds which we have already mentioned as underlying the volcanic zone of the Sidlaws and the Ochils, ranging from Balruddery north-eastwards through Myreton, Carmyllie, Turin Hill, and Glamis. *Zosterophyllum* also passes from the Caledonian upwards into the Orcadian group, and occurs along with *Psilophyton* and *Lycopodites* in the flagstone series of Thurso. Passing now to the genus *Parka*, we find that it has an exceedingly limited distribution in the Scottish Old Red Sandstone, being confined to the Caledonian group, and to those beds underlying the volcanic zone of the Sidlaws and the Ochils, having a similar geographical range to *Zosterophyllum*. In a paper in the *Transactions of the Geological Society of Edinburgh*,[1] by Mr. R. Etheridge, junior, the author refers to a specimen of *Parka decipiens*, in the collection of Mr. Henderson, from the upper Silurian of the Pentland Hills. It has also been recorded from the Kidderminster beds of England; so that *Parka* may be considered as characteristic of the Upper Silurian and Lower Old Red Sandstone rocks.

It will thus be seen that, while *Psilophyton* and *Zosterophyllum* are common both to the Orcadian and Caledonian series, *Lycopodites*, on the other hand, is confined to the Orcadian series alone. *Parka* may be said to be limited to the Caledonian series, with the exception of the Pentland and Kidderminster specimens, which we have not seen, and of whose value in determining the geological distribution of the plant we cannot therefore speak. Regarding the value of *Psilophyton* in the question of the relative ages of the

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[1] *Trans. Geol. Soc. of Edinburgh*, vol. xi. p. 314.

Orcadian and Caledonian series, it would be well to bear in mind that the genus occurs in the Lower, Middle, and Upper Sandstones of Gaspé and New Brunswick. *Zosterophyllum* seems to be common to both areas.

It is, however, when we consider the general facies of the Orcadian flora with that of the Caledonian that we find in the Caithness flags *Lycopodites*, and the remains of plants evidently allied to *Lepidodendron* and *Calamites*, also ferns, shadowing forth, as it were, the coming Carboniferous flora, and none of which species are to be found in the Caledonian series. On the other hand, in the Caledonian group we find quite a distinct flora, having an upper Silurian facies, such as *Parka*, *Pachytheca*, and *Arthrostigma*, none of which are known to pass upwards into the Caithness beds. It is when we carefully weigh this evidence with that derived from the fish fauna of the two areas, and their respective petrological and stratigraphical characteristics, that we are driven by the overwhelming evidence to the conclusion that they represent two distinct periods in geological time, of which the Orcadian is the younger, while the Caledonian is the older of the two areas.

However paradoxical it may appear, we have reason to believe that the occurrence of so-called ganoidian fishes—of a fresh-water type—in the Old Red Sandstone, affords the strongest evidence in favour of its marine origin. That recent representatives of the ganoids of the Old Red Sandstone inhabit rivers and lakes of the globe, is by no means a proof of the fresh-water origin of the latter fishes. The immense interval of time implied by the comparison renders its value somewhat problematical. Sir A. Geikie, in referring to the fishes of the Old Red Sandstone, says: "That some of the fishes found their way to the sea, as our modern salmon does, is indicated by the occasional occurrence of their remains among those of the truly marine fauna of the Devonian rocks."[1]

The life history, however, of the salmon presents evidence of a somewhat different kind; for we find that the *Salmonidae* made their appearance for the first time in the Chalk of the Cretaceous system,[2] which would rather indicate a migration *from* the sea. In like manner, the life history of these obscure representatives of the ganoids of the Old Red Sandstone would probably show that they preserved their existence "in the struggle for life" by a successful adaptation to new surroundings—namely, fresh-water conditions—while their less-favoured contemporaries succumbed.

The large number of fish-remains entombed in the Caithness flags indicates a widespread and sudden destruction of life. Earthquake shocks, the discharge of mephitic gases, and heated waters, have been respectively suggested as the cause of the catastrophe. But whatever the agent of destruction may have been, it apparently came in from an outside area, sweeping before it the fishes of the Old Red Sandstone of Caithness inward towards the shallow shores, where they perished. In referring to the flagstone quarry of Achanarras and its contained fish-remains, Dr. R. H. Traquair states that in the lower bed, two and a half feet in thickness, "there all the species in the list occur almost indiscriminately."[3] It is impossible to conceive the manner in which dead fishes could be preserved entire, during the formation of sandstones and shales of several feet in thickness, in a *tideless fresh-water lake*. But a shallow seashore, presenting broad stretches of sandbanks and mud-flats, would afford a more adequate medium for this purpose. The diurnal tides, on the one hand, laden with sand and mud in their ebb and flow, would undoubtedly cover up immense numbers of the fishes in question; while, on the other, the antiseptic properties of salt water would tend to their preservation, even for some time afterwards.[1]

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[1] *Classbook of Geology*, 1890, p. 262.

[2] Günther, *Study of Fishes*, 1880, p. 631.

[3] *Proc. Roy. Phys. Soc. Edinburgh*, vol. xii. p. 283.

With regard to the introduction and geographical distribution of the fishes of the Old Red Sandstone, the case of the "Lake theory" displays conspicuous weakness. The Eurypterids and Cephalaspidians of the Upper Silurian are in evidence; but of the genera *Osteolepis*, *Dipterus*, *Glyptolepis*, and other fishes of the Old Red Sandstone, no undoubted plates or scales occur in the preceding formation. The question therefore arises, whence came these highly organized fishes of the Old Red Sandstone? More especially, from what fresh-water region did they migrate? Not only so, but, as the same genera of fishes occur in the Devonian of North America and the St. Lawrence basin, we have an equal right to know by what fresh-water pathway of distribution they were enabled to migrate some 3000 miles between one point and another.[2]

But, so far as these questions are concerned, the advocates of the "Lake theory" have maintained an ominous silence. Some eminent palaeobotanists have advocated the view of an Arctic origin and southward migration of the flora of the globe; while Dr. A. Wallace also believes "in the northern origin of both the fauna and the flora of the world."[1] The simultaneous occurrence of ganoidian fishes of the same genera and species in the formations of North America and Britain, as well as in the Devonian of Russia and Central Europe, seems also to indicate a boreal origin and southward migration of the fishes of the Old Red Sandstone. In this connection the genus *Acanthaspis* (Newberry), of the Devonian of Ohio, is of especial interest. A specimen of this fish from the Lower Devonian of Spitzbergen is figured and described by Mr. Smith Woodward,[2] while Dr. R. H. Traquair mentions its occurrence in the Lower Devonian of Prüm in the Eifel.[3] These discoveries thus show an extremely wide range for this Placoderm of the Devonian.

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[1] *Proc. Perthshire Soc. Nat. Sci.* 1893-4.

[2] *Ibid.*

We find Sir A. Geikie stating that no unequivocally marine fossil remains occur in the Old Red Sandstone.[4] We believe we are correct in assuming that our author refers to the fishes and crustaceans alike as equivocally marine remains. We have, however, seen no reason assigned why Eurypterids and Placoderms of the same genera, which are marine in the later Upper Silurian, and fishes of the same genera and species, which are equally marine in the Devonian of Russia and Central Europe, as well as in the Devonian of North America, should be termed equivocally marine in the Old Red Sandstone.[5]

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[1] Brit. Assoc. Address by Sir J. D. Hooker, 1881.

[2] *Nat. Science*, vol. i. No. 8, p. 602.

[3] *Ann. and Mag. Nat. Hist.* sec. 6, vol. xiv. p. 370.

[4] *Textbook of Geology*, 1882, p. 706. [5] *Ibid.* p. 714.

It has been frequently assumed that the presence of land plants in the Old Red Sandstone is a proof of its fresh-water origin. But, from an *a priori* point of view, no good reason can be assigned against the occurrence of land plants in either the sea, on the one hand, or in inland lakes, on the other. As a matter of fact, plant-remains occur indifferently in the Old Red Sandstone and Devonian. Land plants of the same genera and species are met with in the Old Red Sandstone and Devonian of Europe and North America. In littoral deposits they occur abundantly, but in deep-water deposits they are more sparingly met with. On the other hand, traces of seaweeds undoubtedly occur in the Old Red Sandstone. In the sandstones of Gaspé, *Nematophyton* (with which *Pachytheca* is closely associated) is prevalent. This plant has been referred by Penhallow and Carruthers to the Algae. *Pachytheca* is met with in the sandstones of Murthly[1] and in the Flags of Forfarshire; while in a late edition of Page's *Geology* an undoubted fucoid is figured from the Old Red Sandstone of Roxburghshire. Nicholson also says: "The Old Red Sandstone of Scotland contains a good many fragments supposed to belong to seaweeds."[2]

Perhaps in the Middle Devonian of the Russian formation we find the strongest evidence in favour of the marine origin of the Old Red Sandstone. From the northern to the southern boundary of Russia the Devonian deposits have remained comparatively undisturbed to the present day. In the Russian formation

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[1] See *Nature*, 10th April, 1890.

[2] *Manual of Palaeontology*, 1872, p. 521; also *Annals of Botany*, vol. v. No. xviii. p. 158.

"the Devonian and Old Red Sandstone types appear to be united, the limestones and marine organisms of the one being interstratified with the fish-bearing sandstones and shales of the other."[1] "Indeed, cases occur where in the same band of rock Devonian shells and Old Red Sandstone fishes lie commingled."[2] The lower division of the Devonian being absent in the Russian formation, no crustaceans or cephalaspidian fishes occur; but in the lower part of the system (Middle Devonian) we find the remains of the genera of *Osteolepis*, *Dipterus*, etc., "which are specifically identical with those of the Old Red Sandstone of Scotland."[3] The characteristic *Holoptychius nobilissimus* and *Bothriolepis*, and other fishes of the Old Red Sandstone of Scotland, are met with in the upper division of the Russian Devonian, as well as in the Devonian of North America. In the fish-bearing sandstones of the Devonian of Russia no marine shells occur. This may be generally said of the red sandstones and shales of the Old Red Sandstone of Britain, though in the Welsh area *Conularia* (whose recent representative is a denizen of the deep sea) is met with. It is in the St. Lawrence basin, however, where marine shells are more numerously met with. Sir Wm. Dawson says of the marine shells of the Nova Scotian beds: "With respect to the fossils, I may remark that they are all marine; that they belong to numerous genera and species."[4] "Some of the fine beds (of Gaspé) hold shells of *Lingula* and *Modiomorpha* of Hall."[5] It is interesting to note that "a large lamellibranch, closely resembling the Irish *Anodonta*,"[1] is met with in the Devonian of New York.

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[1] *Textbook of Geology*, A. Geikie, 1882, p. 703.

[2] *Ibid.* p. 704.

[3] *Ibid.* p. 704.

[4] *Acadian Geology*, 1855, p. 315.

[5] *Report Geol. Surv. Canada*, 1871, p. 4.

We freely admit that the geological opinion of the present day is largely in favour of the fresh-water origin of the Old Red Sandstone. The unique character of the strata, the presence of well-defined lake boundaries, and the absence of marine fossil remains, have been freely assumed, whilst supporting evidence is conspicuous by its absence. In the Cambrian formation of Wales we find large zones of red sandstones and conglomerates, rivalling, if not exceeding, in extent similar deposits which characterize the Old Red Sandstone of Scotland. The so-called boundaries of lake basins of the Old Red Sandstone would be somewhat difficult to find; for (if we may use the term) they appear to be "of a one-sided order." In the Welsh area, the South of Ireland, and the North of Scotland, the Old Red Sandstone runs out to sea; while in Midland Scotland, if the Old Red Sandstone, thrown down by the great fault which stretches across the country from Ayrshire to Midlothian, were raised to its original position, it would show a south-eastward trend, towering some 12,000 feet over the highest peak of the Southern Uplands.

The marine denudation of the crystalline schists of the Highlands of Scotland is not in dispute, but Ramsay and Geikie have assumed a subsequent lake or fresh-water denudation. The conformable deposition, however, of the Old Red Sandstone upon the preceding Upper Silurian deposits in the counties of Edinburgh and Lanark, in the Welsh area, and in the St. Lawrence basin, precludes any such idea; for, from the base of

[1] *Textbook of Geology*, A. Geikie, 1882, p. 706.

the Upper Silurian, to the top of the Lower Old Red Sandstone, the sequence of these deposits is unbroken. It therefore follows that the denudation of the rocks of the Highland area being marine, the equivalent deposits occurring in the Upper Silurian and Lower Old Red Sandstone are equally marine. We find in the Moray Firth area a large stratum of yellow *saliferous* sandstone, interbedded with shales containing remains of Old Red Sandstone fishes.[1] This stratum of *saliferous* sandstone is well exposed in the precipice of the Burn of Eathie, near Cromarty, and we think but one conclusion alone can be drawn therefrom—that the formation and its contained fish-remains were marine. The widespread occurrence of so-called fresh-water fishes of the same genera and species in the Devonian of Russia, Central Europe, Britain, and North America, renders the "Lake theory" view of the fresh-water origin of these fishes utterly untenable. Finally, we feel justified, upon both physical and palaeontological grounds, in concluding that the Old Red Sandstone and Devonian, in their respective littoral, shallow-water, and deep-sea deposits, represent the one Devonian system, *which is marine.*

[1] *The Old Red Sandstone*, 4th ed. 1850, p. 285.

CHAPTER X

THE PLUTONIC ROCKS AND DYKES OF THE HIGHLANDS

> The rocks are of that sort called Primitive by the mineralogists, which always arrange themselves in masses of a rugged gigantic character; which ruggedness, however, is here tempered by a singular airiness of form, and softness of environment: in a climate favourable to vegetation, the gray cliff, itself covered with lichens, shoots-up through a garment of foliage or verdure; and white, bright cottages, tree-shaded, cluster round the everlasting granite.
>
> CARLYLE.

THE crystalline schists of the Grampians have been penetrated at numerous localities by intrusive bosses and sills of plutonic rocks, and by dykes. The most important bosses are those seen in Glen Tilt, Glen Lednock, and near the head of Loch Lomond on Garabal Hill and a considerable area westward.

Undoubtedly the most striking feature of these later intrusive rocks, and one which has long been known, is the association together, in one plutonic mass, of various members of the two extreme types of acid and basic igneous rocks. Thus at Carn Chois, in Glen Lednock, we have a granite and a diorite intimately connected together; while at Tomnadashan, on Loch Tay, a similar relationship is seen to exist between a granitite and a mica-diorite. Again, at the head of Loch Lomond, on the confines of Perthshire, Argyllshire, and Dumbartonshire, there is a well-known example of the association together, in one plutonic complex, of rocks of an acid, basic, and ultrabasic type.

Within the last few years, principally through the influence of a valuable paper by Mr. J. R. Dakyns and Dr. J. J. H. Teall, published in the *Quarterly Journal of the Geological Society* for the year 1892, it has come to be recognized that the association together of these representatives of the two extreme types of igneous rocks cannot be looked upon as representing two distinct and separate acts of plutonic intrusion. On the contrary, the evidence seems to show that they have been separated out from the same magma.

The area described in the paper is that occupied by the plutonic rocks of Garabal Hill and Meall Breac, near the head of Loch Lomond. The rocks seen in this district vary from the most acid to the most basic type, and include a biotite-granite, characterized by the presence of large porphyritic crystals of flesh-coloured orthoclase felspar, often twinned on the Carlsbad law, and measuring sometimes as much as two or three inches in length. These crystals are more common in some parts of the granite than in others. Zonal structure is very common in the felspar, the inner zones being of a darker colour than the outer ones. The sides of the zones often contain small inclusions of biotite, which lie with their longer axes parallel to the direction of the zoning. Biotite, hornblende, and quartz make

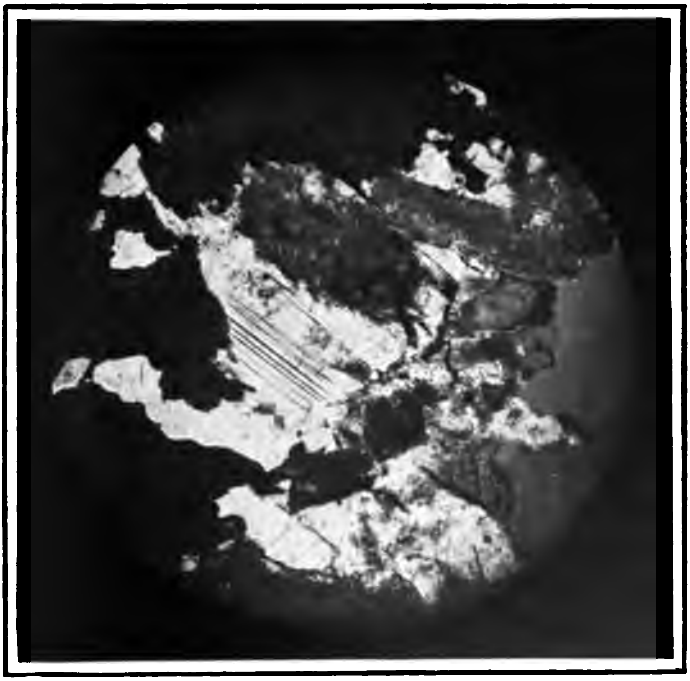

Fig. 21.—Tonalite. Garabal Hill. (Magnified 40 dias. Crossed Nicols.)

Photo. by Jas. B. Corr.

up the remainder of the rock. The quantity of the last-mentioned mineral varies to a considerable extent, and is not always conspicuous in hand specimens. Sphene and zircon occur as common accessory minerals, the former in well-developed large brown crystals. The rock evidently belongs to the variety of granite known as granitite, which is characterized by the presence of much plagioclase, with a black mica, and containing no original white mica. The microscopic structure of the granite is shown under crossed nicols in Fig. 20. Dark basic inclusions, most of which appear to be diorite, and measuring from one to two feet in diameter, occur in the granite.

In many places the granite is seen to pass into tonalite (quartz-diorite), whose microscopic structure is shown in Fig. 21, while the south-eastern margin of the complex is flanked by a belt of diorite, which graduates into such ultrabasic rocks as wehrlite, peridotite, serpentine, and other compounds. Fig. 22 shows a microscopic section of peridotite. The minerals present are augite, olivine, serpentine, and magnetite, the two latter being derived from the decomposition of the olivine. Felspar is absent. Very little fresh olivine remains, and even when fresh the rocks seem to have contained but little olivine. The colour of these rocks varies from white in the thin veins of eurite, to black in the peridotite and serpentines. It is, of course, mainly determined by the relative proportions of the ferro-magnesian and felspathic constituents. As a rule, the rocks of the complex are sufficiently coarse-grained to enable the constituent minerals to be easily recognized; the granite, however, is the only rock which is distinctly porphyritic. The tonalites, diorites, and peridotites consist of individuals of a fairly uniform size.

Andalusites in brown prisms, measuring in some cases half an inch in length, occur in the schists at their point of contact with the plutonic rocks, and undoubtedly indicate that they have been subjected to a certain amount of contact metamorphism. Mr. Clough has also pointed out that the albites in the albite-schists have received a pinkish tint, and he attributes this change in colour to the oxidation of the magnetite specks enclosed within them. Two other well-known contact minerals have also been met with in the schists. These are sillimanite and cordierite.

At some places it is possible to draw a distinct line of demarcation between the diorite and the tonalite; but at others the transition from one rock to another is so gradual as to make any such sharp distinction impossible. The rocks which were formed first were the peridotites, these being followed in order of increasing acidity by diorites, tonalites, and granites. Narrow veins of felspar and quartz, with but sparing ferro-magnesian constituents, penetrate the granites and tonalites; these represent the most acid portion of the magma.

Messrs. Dakyns and Teall say: "The south-eastern portion of the plutonic belt is more basic than the north-western. At certain points along the edge of the boss the diorite and tonalite are seen to invade the surrounding schists, sending veins and strings into the latter, and in some cases completely isolating blocks of the schist." The area occupied by the granites is largely in excess of that occupied by the diorite. "Taking the whole plutonic area as amount-

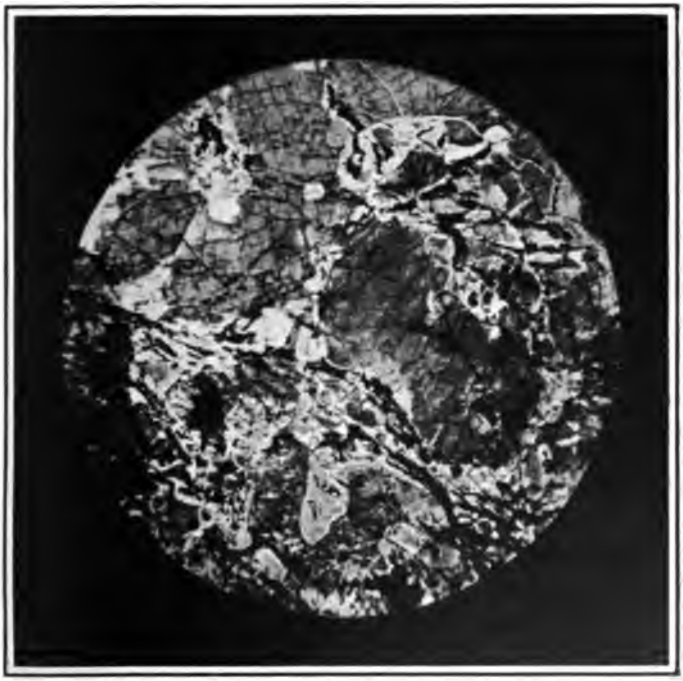

FIG. 22.—Peridotite. Garabal Hill. (Magnified 40 dias.)

Photo. by JAS. B. CORR.

ing to twelve or thirteen square miles, say twelve and a half, ten of these are occupied by granite and only two and a half by diorite." Diorite, therefore, only forms one-fifth of the total area. The area occupied by the ultrabasic rocks is exceedingly small, amounting at the most to one-eighth of a square mile.

The hypothesis put forward by Messrs. Dakyns and Teall, to account for the association in one mass of such a variety of igneous rocks, is, that they were all originally intruded as one magma. They believe that a careful study of such a complex of plutonic rocks leads to the conclusion that they have been produced by a process of differentiation during the consolidation of one original magma; the oldest rocks being the peridotites, as their minerals were the first to form in the plutonic magma. With the advancement of the process of consolidation, a series was developed of rocks of increasing acidity, viz. diorites, tonalites, and granites, the mother liquor being represented by the most acid rock, consisting of quartz and orthoclase, which was formed after the other constituents had separated out. This theory of magmatic differentiation has received the support of such eminent petrographers as Brögger, Vogt, Rosenbusch, and Iddings, and was first applied by Teall to account for the varied types of rocks found in the plutonic complexes of the Scottish Highlands.

It would be impossible to discuss here the various theories that have been advanced to explain this magmatic differentiation, but they may be all grouped under three heads: (1) Differentiation by crystallization; (2) differentiation by diffusion; (3) differentiation by liquation. The first of these views, the hypothesis of differentiation by crystallization, proceeds upon the principle that the mineral components of a rock are known to crystallize out according to the law of decreasing basicity, so that those with a high specific gravity would be the first to form in the molten magma. It is further supposed that the action of gravity would tend to accumulate the more basic materials in the lower part of the magma, and in this manner a separation into a more basic and a more acid portion would take place. According to Becker, crystallization has taken place upon the walls of the reservoir, and in this way the occurrence of the more basic portion of these intrusions near the boundaries, and the more acid near the centre, is accounted for.

The second of these views, differentiation by diffusion, is based upon Soret's principle, that the part of a solution nearest its saturation point moves towards the cooling surface; and as we have already seen that the basic minerals are the first to crystallize, the basic saturated portion of the magma just before crystallization would tend to move towards the cooling surface, and so a differentiation of the magma would take place.

Lastly, in the theory of differentiation by liquation we have a very suggestive explanation of the phenomena as exhibited by these plutonic complexes. It is a well-known fact that two solutions can mix freely with each other at certain temperatures, constituting a perfectly homogeneous liquid. If the temperature be lowered the liquid is capable of separation into two solutions which cannot mix. It is supposed, then, that in the cooling of the original homogeneous magma a stage would be reached when it would be separated into two distinct magmas, which would finally consolidate into rocks of widely different types.

Whatever be the true explanation of the formation of these plutonic complexes and the phenomena connected therewith, the process seems to correspond very closely with Herbert Spencer's famous definition of evolution: "A continuous change from an indefinite incoherent homogeneity to a definite coherent heterogeneity by successive differentiations and integrations."[1]

We now turn to a consideration of the plutonic complex seen at Tomnadashan, a hamlet situated on the southern shores of Loch Tay, about two miles to the north-east of Ardeonaig and seven and a half to the south-west of Kenmore. Here the garnetiferous schists, lying below the Loch Tay Limestone, have been invaded by an irruption of plutonic rocks, which cover an area extending from the shores of the loch up to about the 900 feet contour line.

The great mass of the rock, and that part of it which comes in contact with the surrounding schists, resembles in external appearance the ordinary grey dolerite seen in the neighbouring Tertiary dykes. Where it comes in contact with the surrounding schists it may be observed that a certain amount of contact metamorphism has been superinduced upon the latter rocks. The schists, besides being crumpled, are seen to be baked into a sort of hornstone, or lydian stone. From the occurrence of several isolated patches of this dark rock upon the hillside it is also evident that the schists have been penetrated by apophyses and strings sent out from the main mass.

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[1] For a short summary of the most recent views upon the crystallization of rocks see an interesting paper by Mr. F. Mort in the *Transactions of the Geological Society of Glasgow*, vol. xii. p. 311.

Examined microscopically, it is evident that this rock, though resembling dolerite externally, is of quite a different character, for it is at once seen to be made up of long prism-shaped crystals of plagioclase, showing repeated twinning on the albite type. A dark idiomorphic mica, probably biotite, occurs, and a pale brown augite in well-developed crystals, together with magnetite and pyrite as accessory iron ores. This rock, as Messrs. Cadell and Wilson have pointed out, may be provisionally classed with the mica-diorites. Fig. 23 shows the mica-diorite in contact with the acid rock.

Within this mass of intrusive basic rock, and never, so far as we have been able to find, passing through the kersantite into the surrounding schists, occurs a rock of wholly different character from that just described. It is of a strongly-marked pink colour, contrasting most effectively with the dull sombre colour of the basic rock. It is of a granitoid character, being in many cases quite coarsely crystalline, and exhibiting large phenocrysts of orthoclase. The rock consists of orthoclase, quartz, mica, and some plagioclase, and may be classed as that variety of granite known as granitite. The microscopic structure of the rock is shown in Fig. 23. It seems to us that the bulk of this more acid rock has been concentrated towards the centre of the surrounding basic rock. Along the shores of Loch Tay numerous clear sections show the intimate association of the two rocks, the mica-diorite and granitite being seen to pass into each other in the form of strings, veins, and large masses, so that it

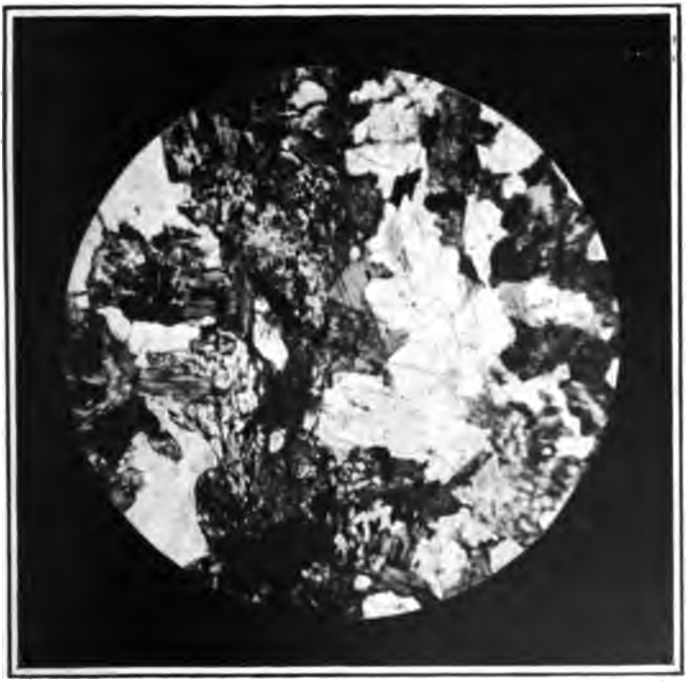

FIG. 23.—Granitite and Mica-diorite. Tomnadashan, Loch Tay.

Photo. by JAS. B. CORR.

seems almost impossible to attribute a priority of intrusion to either of the two rocks. Messrs. Cadell and Wilson, in their paper upon the Tomnadashan mines, distinctly consider the kersantite to be the older rock, into which the granitite has been intruded at some subsequent period; or, to use their own words, they say that the kersantite has in turn been pierced by a rock of totally different character, veins of which ramify in countless multitudes through the older mass.

It is interesting to note that Mr. F. Ordernheimer, who worked the ores which occur in these rocks for the late Marquis of Breadalbane, says in his paper on "The Mines and Minerals of the Breadalbane Highlands":[1] "The igneous rocks on the south side of Loch Tay are chiefly composed of compact felspar porphyry in the most striking varieties, and of greenstone. Both rocks, porphyry and greenstone, are closely connected at Tomnadashan and Ardtalanaig at about equal distances from the east and west end of Loch Tay. At this place there is quite a mixture, each forming veins and nodules in the mass of the other. This mixture occurs in the middle of the eruption of the greenstone and the porphyry. Towards the borders of the space occupied by these rocks a separation takes place, the greenstone occupying the east side, the granitic porphyry the west. It is not possible to ascribe a previous age either to the greenstone or the porphyry; *they seem to be contemporaneous.* The series of greenstone in porphyry and porphyry in greenstone may be veins of secretion or an accumulation of similar masses in tabular spaces out of a mixed compound of minerals in a molten state."

[1] *Transactions of the Highland and Agricultural Society* for 1841.

Gustav Thost, in a paper contributed to the Geological Society of London in 1860, gives a description of the mines at Tomnadashan, and advocates the view that the granitite, or, as he calls it, the porphyry, was erupted into the greenstone after the consolidation of the latter, and consequently at a later period. He thus at once traverses the position previously taken up by Ordernheimer. A quotation from his paper will explain his position. He says: "All the facts there obtained support the supposition that after the mica-schists had been broken through by the greenstone a powerful vein of porphyry was erupted, for the greenstone, while remaining unchanged in position and character on the east and west sides of the porphyry vein, has near its middle part not only been deranged by mechanical force, but has also been often altered by chemical agency into a substance exhibiting the mixed characters of greenstone and porphyry, with transition from one to the other."

The above quotation leaves us in no doubt as to the views of its author; and, notwithstanding the fact that he had recognized the gradual transition of one rock into the other, still he believed that they represented two distinct periods of intrusion, the granitite having been erupted into the kersantite long after the former had become consolidated.

We find Messrs. Cadell and Wilson, in the paper already referred to, adopting a similar theory to account for the phenomena seen at Tomnadashan.

Fifty-one years after the publication of Ordernheimer's paper we find his views revived by Messrs. Dakyns and Teall in the paper already mentioned; and, so far as we can make out, his interpretation of

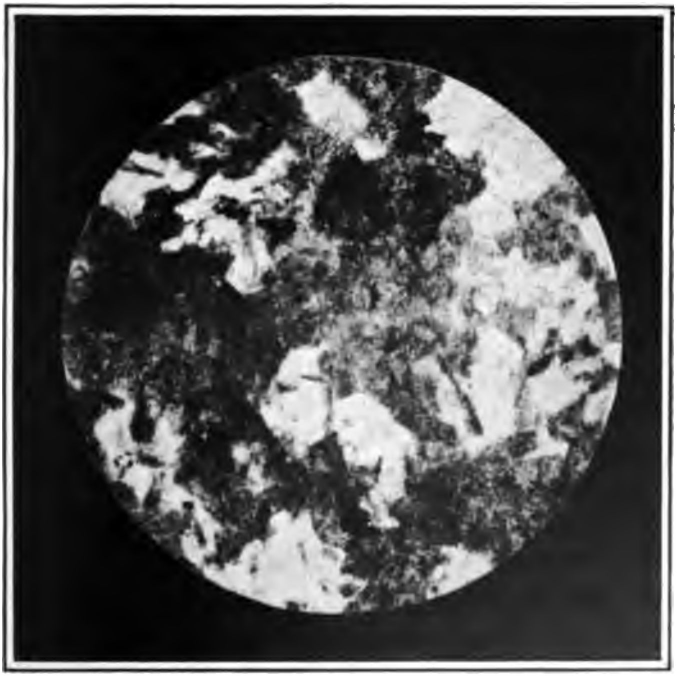

FIG. 24.—Felsite. Ardeonaig, Loch Tay. (Magnified 40 dias. Crossed Nicols.)

Photo. by JAS. B. CORR.

the phenomena seen at Tomnadashan seems to have been the correct one. Thus, it is a remarkable fact that the acid rock never seems to pass from the basic rock into the surrounding schists. If the acid rock were a later intrusion, there would be no reason for its being confined to the surrounding basic rocks; whereas, on the supposition that they had both segregated from the same magma, this relationship is at once accounted for. Again, notwithstanding the statement made by Thost that the acid rock is often seen to alter the basic rock, both mechanically and chemically, when it comes in contact with it, we have never been able to find any traces of contact metamorphism. When examined microscopically, the kersantite in contact with the granitite exhibits exactly the same character as it does when over a mile away from the actual contact. In some cases, especially where the granitite has penetrated the mica-diorite in fine veins and strings, the line of demarcation between the two rocks is an exceedingly sharp one, as may be seen from the micro-photograph. In these cases the injection of the granitite into the kersantite may belong to a slightly later period in the cooling of the magma; but where the main mass of acid rock passes into the basic rock, there is clear evidence of a gradual transition from the one to the other. This appears to us to be more easily accounted for on the supposition that they have been formed by the cooling down of one magma, than on the principle that they represent two separate intrusions of rock; and we hold with Ordernheimer that there is no evidence to show the priority in time of either of the two rocks involved in the complex.

The ores found in association with these rocks are chiefly copper pyrites (chalcopyrite) and grey copper ore (tetrahedrite), the former being usually massive, the latter often occurring in well-developed tetrahedra. Iron pyrites in cubes, and in small pyritohedra, accompanies the copper ores; and scales of molybdenite are found in quartz veinlets traversing the granite. It has also been stated that silver ore was at one time found at Tomnadashan. The ores principally occur in the granitic rock, and when they are present, the rock is usually in an extremely decomposed condition. They were mined for about twenty years by the late Marquis of Breadalbane.

Another important area of plutonic rocks is that developed around Carn Chois. They are well seen in the streams that enter Glen Lednock from its eastern side. This area presents much the same petrographical characters as those already described, and it will therefore be unnecessary for us to enter into any details regarding these rocks. The basic rock here, as at Tomnadashan, seems to be in the greatest bulk and to cover the greatest area. It can be seen at various points in the bed of the Lednock, from above the Devil's Cauldron to near Ballandalloch. Still further up the valley, it has been quarried near the farmhouse of Innergeldie, having been used to build the Melville Monument. From this point it can be traced still further up the glen to near the bridge at Spout Rollo. The streams descending from the side of Ben Chonzie, such as Innergeldie burn, also exhibit fine sections of the more basic rocks. Under the microscope the diorite shows a holocrystalline granitoid structure, being composed of a plagioclase felspar and green

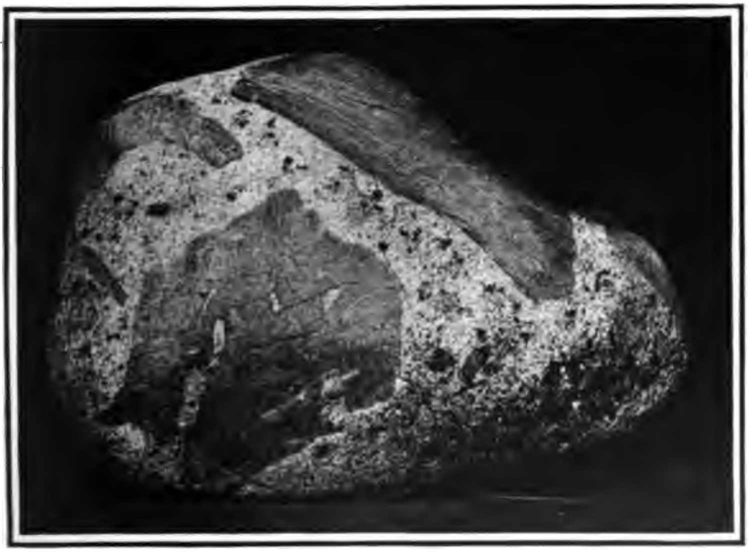

FIG. 25.—Boulder of Acid igneous rock containing fragments of Clay Slate. Glenalmond.

Photo. by A. S. REID (*magnified*).

hornblende. At some points, abundant quartz is present, and most likely marks the transition point between the granite and the diorite.

In the Lurg burn and its various branches to the east, descending from the sides of Carn Chois, the central core of more acid rock may be well seen. The granite contains both plagioclase and orthoclase felspar. The other constituents are quartz, biotite, and hornblende, with magnetite as an accessory iron ore. The granitic ground mass is somewhat fine in texture, and through it are distributed small porphyritic crystals of orthoclase.

Where the diorite comes in contact with the surrounding schists, a certain amount of contact metamorphism can be observed. At many points the diorite may be seen to send veins of a considerable size into the surrounding sedimentary rocks, baking and altering them.

A small area in Glen Banvie, about three and a half miles north-west of Blair Atholl, is occupied by these younger granites and diorites. The acid rock usually consists of a rather coarse-grained granite in which both hornblende and biotite are present. Orthoclase and plagioclase occur in equal abundance, and are usually of a white, grey, or pink colour, the whole being set in a paste of quartz. The hornblende is usually idiomorphic and of a dark green colour, but the biotite rarely presents well-marked crystalline boundaries. The accessory minerals are apatite, sphene, zircon, and iron-oxides.

Towards the north and east, the granite passes into diorite. The transition is a gradual one, the intermediate rocks, as in the areas already described, being tonalites. As a rule, the intermediate rocks are finer-grained than the diorite, and the presence of well-formed crystals of plagioclase and hornblende gives them a slightly porphyritic appearance. Biotite and hornblende are the ferro-magnesian constituents of these rocks, the former mineral being much less abundant in the diorites than in the tonalites. Orthoclase and quartz are, of course, more common in the acid rocks, and gradually diminish in importance as the rock assumes a more basic character.

Dykes and sills of acid and intermediate igneous rocks are more or less common throughout the whole of the Highlands. Numerous fine examples are exposed in the valley of the Garry above Blair Atholl, and in the neighbourhood of Schichallion. The officers of the Geological Survey have pointed out that, though none of these can be shown to proceed from the later granite intrusions, which have just been described, yet there can be no doubt as to their genetic connection with these intrusions, as the peculiarities of their distribution can be explained by their relationships to such granitic intrusions as occur at Ben Alder, Glen Tilt, and Ben Chonzie.

A notable feature of these dykes is their general north-easterly parallelism. Their direction thus coincides with the strike of the folds in the schists. For this reason they are seldom seen to cut each other, but, in some instances, this is known to occur. Being usually harder than the surrounding schists, they have yielded less readily to the action of the denuding agents, and can often be seen to stand up in knolls and ridges above the general level of the ground.

Besides occurring as dykes, these later intrusions

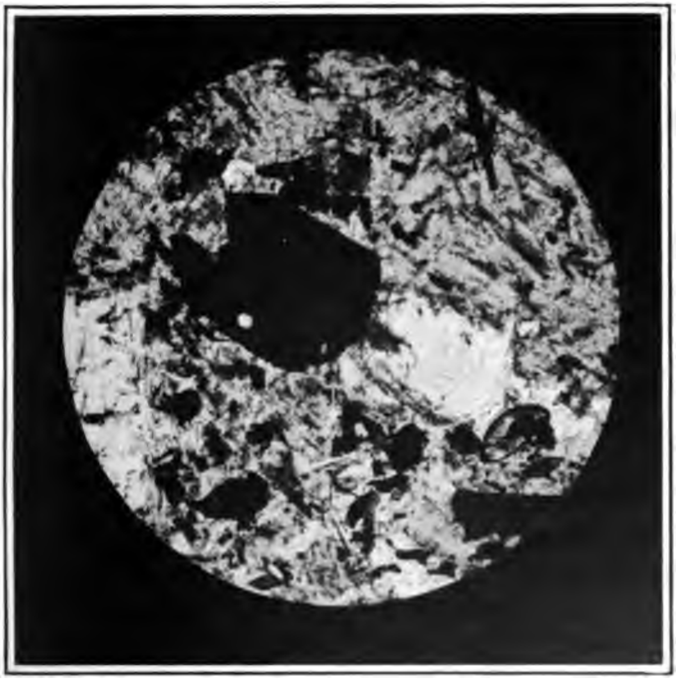

FIG. 26.—Diorite Porphyry. Glen Tilt. (Magnified 40 dias.)

Photo. by JAS. B. CORR.

can also be observed rising along the foliation planes in the schists, especially where these are inclined at high angles. A large area is occupied by these sills near the head of Glen Lednock and along the shores of Loch Tay. One intrusion stretches from Glen Tarken, on the shores of Loch Earn, northwards to Meall na Creige, overlooking Loch Tay. Another extends from the head of Glen Beich to the shores of Loch Tay at Ardeonaig: while a third runs along the southern shores of Loch Tay from Ardtalanaig to Ardradnaig, rising up the hillside to the summit of Beinn Bhreac. Further westwards, another extensive sill crosses the valley of the Dochart near Luib, running northwards by the Auchlyne Burn and southwards by the Luib Burn. Another of these large sills stretches from the lower end of Loch Rannoch by the west side of Beinn a' Chuallaich to the Errichdie Water above Trinafour. Numerous other minor sills and dykes also occur, but these need not be given in detail.

The rocks of these larger sills are mostly quartz-porphyries or felsites. In the former case, the rock usually consists of porphyritic crystals of quartz or felspar set in a ground-mass of the same minerals. This ground-mass presents a finely crypto-crystalline structure, the individual granules of the felsitic matter being so minute as to be scarcely recognizable in many cases, even with high powers of magnification. Micro-pegmatitic structure is not uncommon. The porphyritic constituents consist of colourless bi-pyramidal crystals of quartz, often highly corroded, and containing liquid inclusions. The felspars usually show well-defined idiomorphic crystals, which may be either transparent, or colourless, or of a pale pink, red, or grey colour.

The felspars readily decompose into kaolin, the decomposition most commonly beginning at the centres and proceeding outwards.

The felsites are marked by an entire absence of any porphyritic constituents, and are usually of a pink or orange colour. Seen under the microscope in thin sections, they exhibit a microgranitic and often micropegmatitic structure. Both these types can be observed in the Glen Lednock and Loch Tay area. The microscopic structure of these fine-grained felsites is shown in Fig. 24.

The Beinn a' Chuallaich sill, besides containing large crystals of plagioclase felspar and quartz, also contains hornblende and biotite. All these minerals are in perfectly idiomorphic crystals, and are set in a ground-mass consisting of a microgranitic aggregate of felspar and quartz, in which micropegmatite occasionally appears. Fig. 26 shows a section of diorite-porphyrite from a dyke in Glen Tilt, near Blair Atholl. The rock is distinctly porphyritic, the phenocrysts being plagioclase, biotite, and perfectly idiomorphic hornblende. The ground-mass is holocrystalline, and is a fine-grained aggregate of hornblende, felspar, and magnetite, with a little quartz and sphene.

Dykes and sills of lamprophyre, including kersantites, vogesites, and spessartites, are also to be met with throughout the Highlands. Fig. 27 shows a section of lamprophyre from a dyke which crosses the Garry near Struan. The rock is much decomposed, the chief minerals present being biotite, quartz, and calcite. The calcite is, of course, secondary. The quartz is idiomorphic, and, from its relations with the calcite, also appears to be secondary. These two minerals

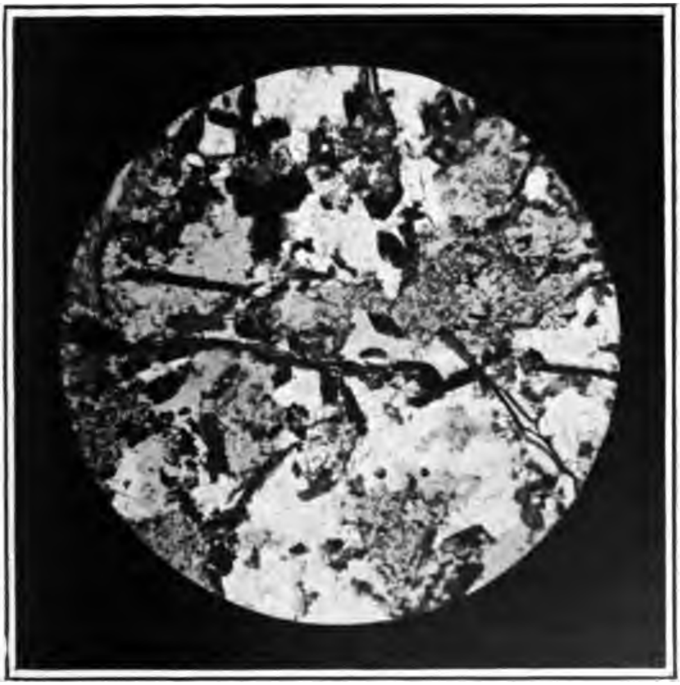

FIG. 27.—Lamprophyre. River Garry, Struan. (Magnified 40 dias.)

Photo. by JAS. B. CORR.

have probably arisen from the decomposition of the original felspar, which is now practically absent. The rock originally was most likely one of the lamprophyres or mica-traps, and was probably a kersantite.

Regarding the age of these granitic masses, and their connection with any known period of volcanic activity, we have, as yet, no very definite information. It will be remembered that Professor Judd, in his second paper upon the Secondary rocks of Scotland,[1] brought forward the view that these plutonic rocks were but the roots of volcanoes laid bare through extensive denudation, and that he attempted to connect them with the volcanic products of Old Red Sandstone age. In this paper Professor Judd also institutes a comparison between the volcanic phenomena of the Tertiary rocks of the Hebrides, and the granites of the Highlands, along with the lavas and agglomerates of central Scotland. He shows that both in the Hebrides and in the southern Highlands the granites are seen to pass upwards into syenite-granite and felsite, and that "unmistakable evidence, both stratigraphical and palaeontological, and of totally independent character in either case, has led us to the conclusion that the subaerial felstone and porphyrite lavas of Lorne, the similar subaqueous lavas of central Scotland, and the intrusive masses of identical ultimate chemical composition in the Grampians, were all formed during the same geological periods—those constituting the latter part of the Palaeozoic epoch." Professor Judd then proceeds to instance the case of Beinn Nevis, for which he claims a similar structure to the Tertiary volcanoes of the Hebrides, which pass from a basal granite, through agglomerate, into a felstone towards the summit.

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[1] "The Secondary Rocks of Scotland," Prof. Judd, *Quart. Journ. Geol. Soc.*, vol. xxx. p. 220, 1874.

Undoubtedly many of the granite masses found in the Highlands must be older than the Old Red Sandstone period, as the conglomerates which lie at the base of that formation are often seen to be composed of granite pebbles and granite detritus. But whether or not we agree with Professor Judd in his reading of the structure of Beinn Nevis, it has always seemed to us that his connecting of these eruptive bosses of plutonic rock with the volcanic series of Lorne and central Scotland, was a masterly generalization ; and the recent work of the Geological Survey in the South-west Highlands has tended to confirm this view.

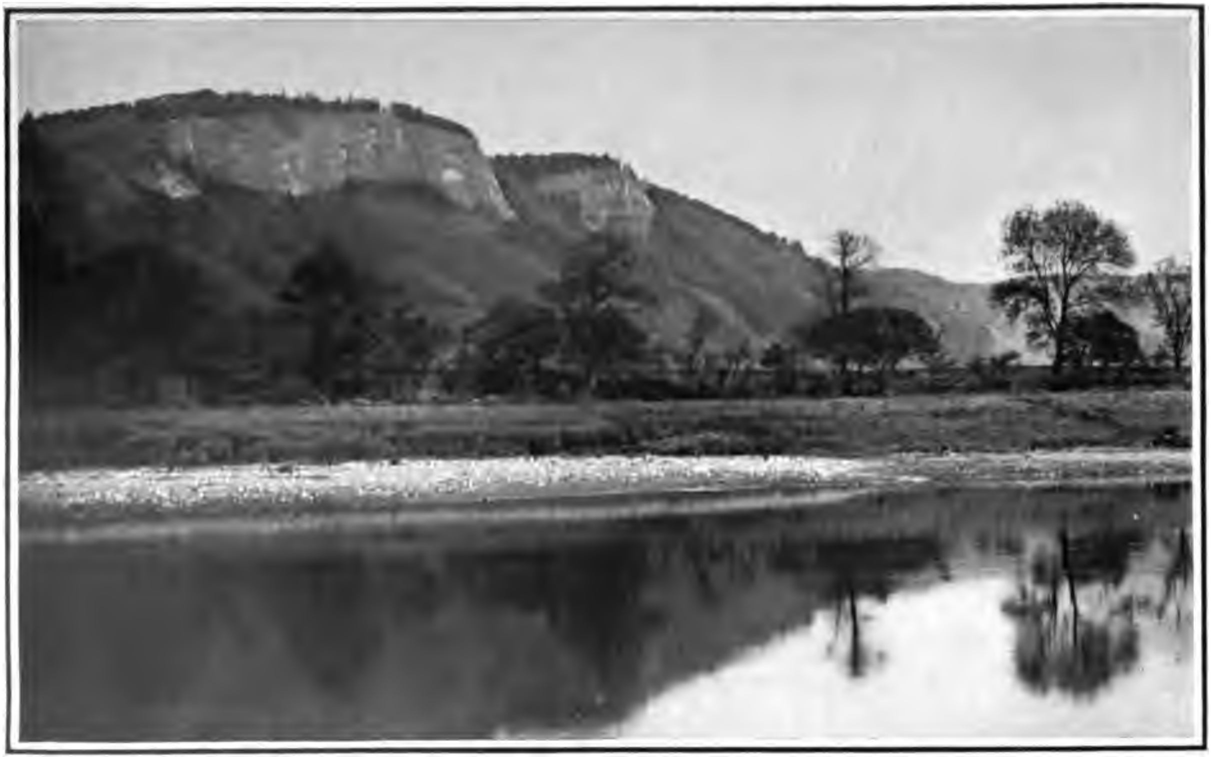

FIG. 28.—The Cliffs of Kinnoull Hill, showing escarpment of Lava Beds (Andesites).

Photo. by WM. ELLISON.

CHAPTER XI

THE VOLCANIC ROCKS OF OLD RED SANDSTONE AGE

> From whose caverned depths aspire,
> In purest folds upwreathing, tost
> Fountains of approachless fire—
> By day a flood of smouldering smoke
> With sullen gleam the torrents pour.
>
> PINDAR, translated by CAREY.

IN Chapter IX. we referred to the great anticlinal fold of volcanic rocks that is to be seen in the Ochil and Sidlaw Hills. We also saw that in the valley of Strathmore there is a syncline of Old Red Sandstone rocks, which overlie these ancient lavas and tuffs, this syncline of sedimentary rocks being separated from the Highland schists by the great boundary fault (see Fig. 10). On the north side of the boundary fault, to the east side of Dunkeld, and in the neighbourhood of Crieff, fragments of the basal conglomerate of the Old Red Sandstone are found resting upon the Highland schists in an unconformable position. Associated with these, occur beds of lava and agglomerate, which seem to represent the thick beds of the Ochils and the Sidlaws in a more attenuated form.

One of the most interesting and striking features of the Old Red Sandstone of Strathmore is this abundant intercalation of ancient lava beds among the sandstones and conglomerates. They lie, as Sir A. Geikie has shown, several thousand feet above the base of the system, and have a total thickness of over 6000 feet. They are chiefly composed of andesites, felsites, and tuffs, and form the main mass of the Sidlaw and Ochil Hills. They are clearly of volcanic origin, and indicate that the ancient sea, in which the Old Red Sandstone sediments were accumulated, must have been dotted over with active volcanic vents, which seem to have arranged themselves in lines conforming to the general trend of the fault systems, which produced the great Midland Valley. From these volcanic vents were poured out great streams of lava, which covered large areas of the sea-floor.

These volcanic beds are well exposed in the Sidlaw and Ochil Hills, where they have been brought to the surface by the great anticlinal fold already referred to. This fold can be well seen from the top of Moncrieff Hill, to the south of Perth. On ascending this hill, which is itself part of the northern limb of the anticlinal arch, we see, on looking down the valley of the Tay, that all the hills belonging to the Sidlaw range have the long slopes of the successive lava flows dipping towards the north-west, and their abrupt mural fronts facing the south-east (see Figs. 28 and 29). Looking towards the south, the Ochil range of hills is seen to present exactly the reverse order. There, the long slopes dip away towards the south-east, and the escarpments face the north-west. This great fold or anticline in the volcanic rocks runs through the Ochil

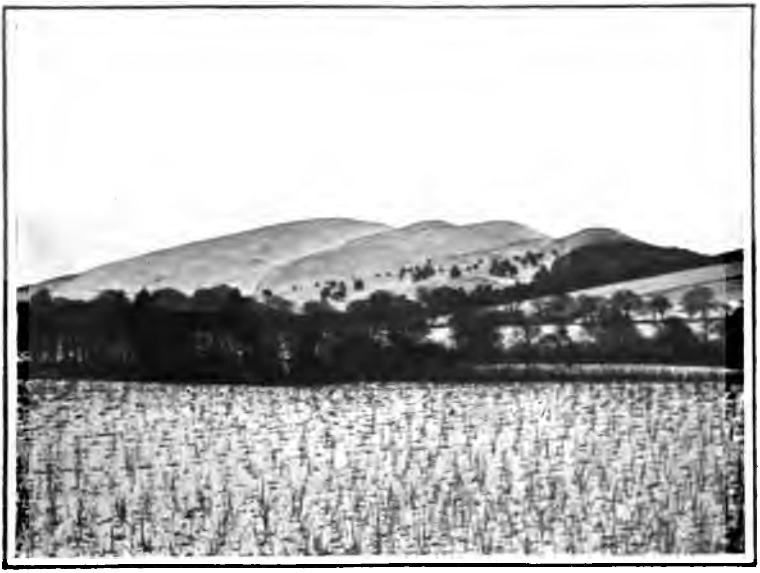

FIG. 29.—Dunsinane Hill, showing interbedded lava flows.

Photo. by ALEX. MACKENZIE.

chain in a north-easterly direction from the neighbourhood of Bridge of Allan, passing along the Firth of Tay through Forfarshire, and entering the sea near Montrose. Its total length is something like sixty miles (see Figs. 10 and 35).

In the chapter on the Old Red Sandstone of Strathmore, we showed how the anticlinal arch of volcanic rocks seen in the Tay valley below Perth has been truncated by two powerful faults. The effect of these faults is the splitting of the volcanic chain in two, one part of which runs along the north side of the Firth of Tay and forms the Sidlaws, while the other part runs along the south side and constitutes the Ochils.

The volcanic rocks of this great anticlinal arch have, in their turn, been covered by the higher members of the Old Red Sandstone of Strathmore, and it has already been shown that lavas occur interbedded with the basal conglomerates seen along the boundary fault. It therefore seems highly probable that the syncline of Strathmore is underlain by these volcanic rocks, and that, in making an estimate of the total area covered by these lava beds, this fact would require to be taken into account.

The outcrop of these lava beds which occur among the basal conglomerates of the Old Red Sandstone can be traced to the south of the boundary fault by Blairgowrie, Murthly, Crieff, and Comrie. There, owing to their stratigraphical position, they do not form such striking features in the landscape as they do in the Ochils and the Sidlaws; but they serve to show that, while the sediments which were being formed at a considerable distance from the sea-shore were being covered by lavas, the conglomerates which were being formed along the edge of the shore were also being overlaid by thick beds of molten volcanic material.

On the south side of the Strathmore syncline, the lowest beds in the volcanic zone are exposed near the Yetts of Muckart, where they are seen to consist of thick beds of very coarse agglomerate, along with which are intercalated occasional lava flows. These pass upwards into thick beds of andesite lava, with here and there a layer of agglomerate. Still higher in the series, the fragmental volcanic rocks again begin to predominate, and eventually the volcanic ejections die out, and are succeeded by sedimentary deposits.

As has already been pointed out, Sir A. Geikie has estimated the thickness of this volcanic group at 6000 feet. He says in this connection: "While the thickest mass of lavas and tuffs lying towards the south-west points to the existence of the most active vents in that part of the area, the actual position of these vents has not been detected. Probably they lie somewhere to the south of the edge of the Ochil chain, under the tract which is overspread with the coalfield. But other, and possibly minor, orifices of eruption appear to have risen at irregular intervals towards the north-east along the length of the lake. Thus there are numerous bosses of felsitic and andesitic rocks among the Central Ochils, some of which may mark the position of active vents."[1] The same writer further points out that as the volcanic anticline is traced towards the north-east, and where it opens out along the Firth of Tay, another group of bosses, or necks, are seen to emerge from the lower members of the sedimentary series.

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[1] *Ancient Volcanoes of Great Britain*, vol. i. p. 305.

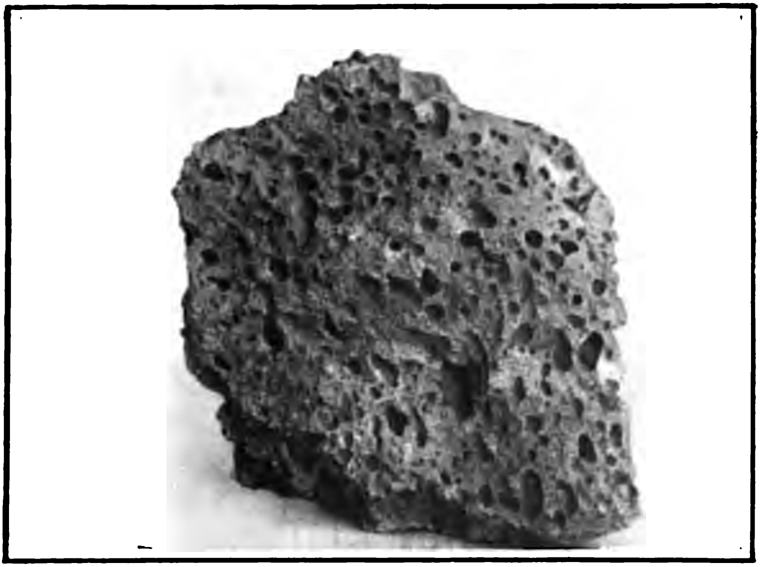

FIG. 30.—Andesite, showing Amygdaloidal Structure. Kinnoull Hill, Perth.

Photo. by ALEX. M. RODGER.

The highest beds in the volcanic zone can be seen in the vicinity of Auchterarder and Bridge of Allan. At these localities they pass upwards into a coarse conglomerate, made up of well-rounded fragments of andesite, which have, most probably, been derived from the abrasion of the underlying and older lava beds, and also, in part, by the accumulation of layers of fragmental volcanic rocks. At Bridge of Allan, and near the county boundary line, specimens of *Eucephalaspis*, *Pteraspis*, and *Scaphaspis* were obtained from a sandstone quarry, the sandstones of which underlie a bed of lava which marks the close of the great volcanic outbursts of the Sidlaw and Ochil Hills. These fossils were described by Professor Ray Lankester,[1] and they seem to occur upon the same fossiliferous horizon as the fish bed of Turin Hill in Forfarshire.

All the structural features which characterise contemporaneous lava flows, can be seen in the volcanic rocks of the Lower Old Red Sandstone of this region. Thus, they are always more or less open in texture, particularly in the upper part of the sheets, which generally present a slaggy appearance, precisely like that of the surface of a recent lava flow. This vesicular structure, as it is called, is due to the expansion of the rock, while still plastic, by the contained steam. These steam holes generally become filled up with various mineral deposits, such as calcite, chalcedony, etc. (Fig. 30). This amygdaloidal structure is very well marked in the volcanic rocks of Kinnoull Hill, near Perth, where the cavities have been filled with quartz. They give rise to the familiar Kinnoull Hill pebbles or agates.

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[1] *Palaeontographical Society*, vols. xvi. (1867) and xxiii. (1869).

The concentric lines, which add so much to the beauty of these, mark the successive layers of the deposit, and may therefore be called lines of growth. In some cases these lavas exhibit a faintly resinous appearance, due to the existence of an undevitrified glassy base. This can be seen in some of the lava flows in the vicinity of Bridge of Allan and at other localities.

The fragmental materials which have been ejected from the volcanic vents, consist of tuffs, breccias, and agglomerates. In the agglomerates and breccias the ejected materials are huddled together in a pell-mell manner, indicating that they have been formed by the blowing up of rocks that had already become consolidated. The fragments vary in size from minute grains up to huge blocks weighing many tons. The tuffs are much finer fragmentary productions, and represent the materials that have been blown high into the air, and which may have floated through it for long distances, eventually settling down more gently and regularly than the larger fragments. They would thus give rise to deposits showing some appearance of regular bedding. Associated with the tuffs, there are often to be found beds of sandstones and conglomerates of ordinary aqueous sedimentation. As the tuffs are traced away from the centres of eruption, they are found to merge into these normal aqueous deposits (see Figs. 31 and 37).

The Old Red Sandstone lavas vary in chemical composition from diabases, in which the silica percentage is about 50, to andesites, in which it rises to 60 per cent. It is interesting to note, as has been pointed out by Sir Archibald Geikie, that the prevalent type of the lava sheets of Lower Old Red

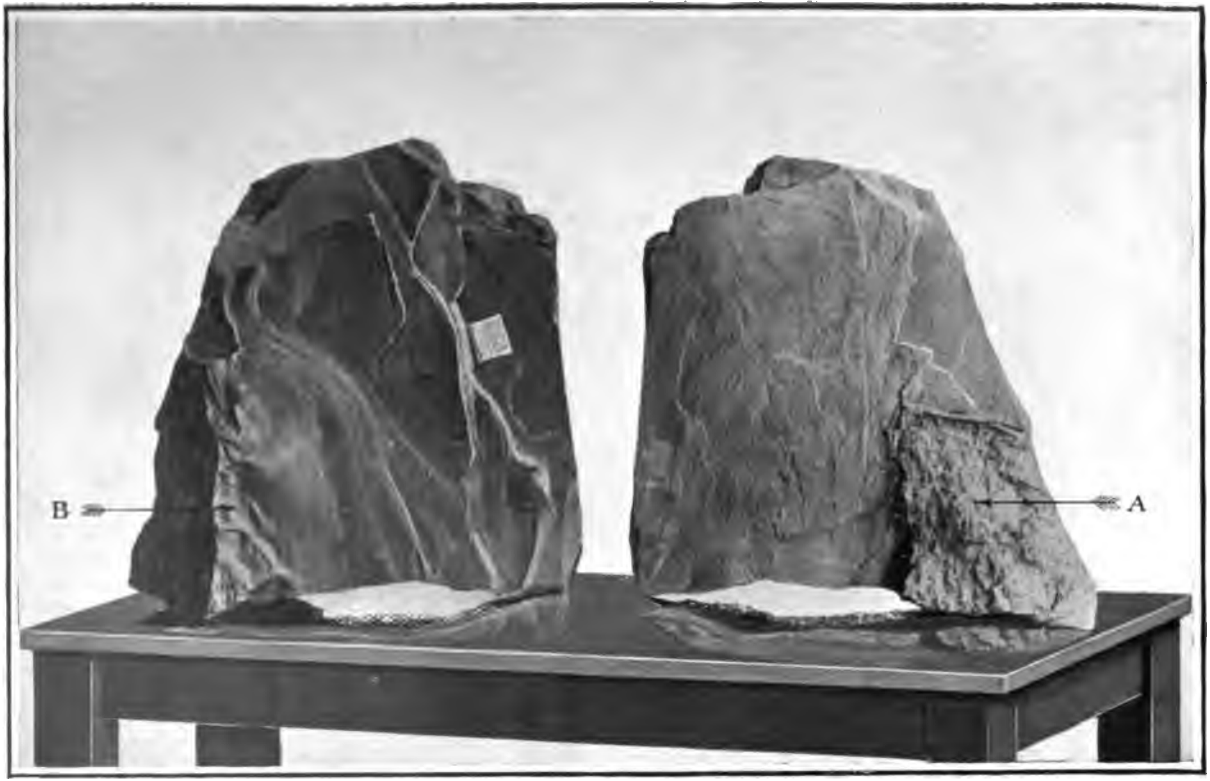

FIG. 31.—Volcanic Tuff, with included fragment of Andesite. Kinnoull Hill, Perth.

A. Fragment of Andesite.
B. Indentation in Tuff, produced by fall of fragment in the volcanic mud.

Photo. by ALEX. M. RODGER.

Sandstone age, presents a character intermediate in chemical composition between the Older Silurian lavas on the one hand, and the younger Carboniferous lavas on the other. Thus, such acid rocks as the rhyolites of the Bala and Upper Silurian period are absent from the Old Red Sandstone lavas. Nor do we find such basic rocks as those which occur in the Carboniferous system.

The andesites are dark-coloured rocks, the colours varying from grey to purplish red, brown, and green, the last being perhaps the most common. They may have a compact, vesicular, or semi-vitreous structure, as has already been pointed out. Mineralogically, they consist of a glassy plagioclase felspar and a ferro-magnesian constituent. On fresh surfaces, minute lath-shaped felspars may often be detected by the naked eye, even in the finer varieties. The pyroxenic constituents are usually much decomposed. Large phenocrysts of plagioclase felspar are abundant in certain localities, these being occasionally accompanied by well-developed crystals of augite or enstatite, which give the rock a porphyritic structure. Microscopically, these andesitic lavas present a glassy base, which, as a rule, has become more or less devitrified by the development of felspathic microlites. Through this ground-mass are scattered the phenocrysts of plagioclase and augite (see Figs. 33, 34 and 36).

Reference may be made to a remarkable example of an undevitrified volcanic glass which was discovered some years ago by Mr. James Durham near Newport on the Firth of Tay.[1] The glass was found in a block of quartz-andesite, or dacite, in a volcanic breccia which had been derived from some neighbouring volcanic vent of Old Red Sandstone age. Professor Judd says of this glass: "It is unique in the case of a rock of such great antiquity that some portions of the glassy base are seen to be quite as free from alteration as any Tertiary or recent obsidian. Most striking and beautiful is the perlitic structure of this remarkable rock. I know of no glass, ancient or modern, which exhibits this structure in greater perfection (Fig. 38). This remarkable rock must be classed as a porphyritic and perlitic mica-dacite glass. It appears that this vitreous variety occurs in scattered nests in the midst of the ordinary stony form. I have seen in the lava streams of Lipari similar angular masses of glass, enclosed in the stony rhyolites, and the appearances in both the ancient and the recent rocks suggest that a brittle glassy rock had been broken up and entangled in a more stony cooling mass, that had assumed a stony character. Subsequently this lava itself appears to have been broken up by a volcanic vent being opened below it, and its fragments thus became enclosed among the ejecta of the later volcano." We are not aware that this interesting rock has yet been discovered in Perthshire, but if careful search were made amongst the volcanic rocks, it might yet be found.

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[1] *Quarterly Journal Geological Society*, xlii. (1886).

At Craig Rossie, near Auchterarder, there occurs a series of lava flows which were formerly mistaken for pyroclastic rocks. In hand specimens, this rock presents a purplish or pinkish-grey colour, which, upon weathering, becomes almost white. Well-defined porphyritic crystals of plagioclase and orthoclase felspar are present, but in many cases they have been much decomposed. Plates of mica and a few small rounded grains of quartz also occur in the rock (see Fig. 39). These minerals are set in a felsitic groundmass, through which are numerous small crystals of felspar. The most striking feature in this rock, however, is the remarkably perfect development of flow structure which it exhibits. This can be well seen even in hand specimens, and is indicated by a series of streaky lines, parallel to which the longer axes of the felspars have been arranged when the rock was in a viscous condition. Fragments of the more basic lavas have been caught up and incorporated in the mass of this more acid type as it flowed over the surface. We shall see presently that this bed was amongst the last eruptions that took place from the vents of the Old Red Sandstone volcanoes. A microsection of this rock is shown on Fig. 39.

It has already been observed that the andesite lavas usually give evidence of having suffered considerable alteration, when they are known as porphyrites. In this condition the augite has been partly or wholly converted into chlorite, and the hypersthene into fibrous bastite, while the felspar, instead of showing a fresh glassy appearance, has become turbid, and eventually passes into kaolin.

An exceedingly interesting section of these volcanic rocks is that which is to be found in the hills of Kinnoull and Moncrieff in the neighbourhood of Perth (see coloured sketch-map). The entire surface of Kinnoull Hill is covered by a series of lava beds well exhibited in the face of the hill. These beds must have a thickness of about 600 feet, and consist principally of andesite lavas, which slope away to the north-west at an angle of about 60 degrees. Here and there, interbedded with the lavas, there occur thin layers of fragmental rocks, a well-known example being that shown in the Dragon's Hole in the cliff face above Lairwell. At this point the fragmental rocks consist of a bed of conglomerate made up of well-rounded pebbles, which, in some cases, are nearly two feet in diameter. This bed of conglomerate is seen to rest on a scoriaceous upper surface of andesite, and is overlaid in a similar manner by another bed of andesite, the bottom part of which exhibits a vesicular structure. A somewhat similar section, showing a series of interbedded sandstones and lavas, was exposed in the Witchill Quarry, and part of it may still be seen in the playground of Kinnoull Public School.

At the base of Kinnoull Hill, and immediately above the Kinfauns Castle carriage-drive, there occurs a series of ashy conglomerates, tuffs, and other volcanic ejectamenta, which stretch across the valley of the Tay and overlie the lava beds of Moncrieff Hill. This horizon of fragmental rocks must have a thickness of something like 250 feet. The same horizon is exposed in the railway cutting at Friarton and on the slopes of Friarton Hill, where the fragmental rocks are seen to alternate with beds of lava. These fragmental beds can also be traced eastwards by Kinfauns Castle, where they are exposed in the Deuchney Burn, through Crossford and Craignorth to near Over Durdie. Both the andesites and fragmental rocks dip towards the north-west and north, and they obviously overlie the volcanic rocks of Moncrieff Hill, which present much the same characters as those seen on Kinnoull Hill, and, together, form part of the great anticlinal arch, which has already been referred to.

Still further to the east than the section just described, another section may be given. It is taken from the Carse of Gowrie through Over Durdie, and across Pole Hill to the neighbourhood of Murrayshall. To the east of Nether Durdie (Fig. 32), the Upper Old Red Sandstone rocks have been thrown downwards against the volcanic rocks by the line of fault seen along the southern front of Moncrieff Hill, Inchyra, and Pitroddie. Crossing to the west of this line of fault, we pass on to the volcanic plateau of the Sidlaws, which has a breadth at this point of about three miles. As in the Kinnoull and Moncrieff Hill section, the rocks all dip towards the north-west, and consist of an alternating series of fragmental rocks and lava flows, the total thickness of the series having been estimated at 2500 feet. The lavas are mostly andesites, which vary in colour from blue and purple to red, and in texture from fine-grained felsitic-looking rocks to lavas with open texture and slaggy-like appearance. At this point there are four distinct horizons of fragmental rocks, which have much the same character as those exposed at the base of Kinnoull Hill.

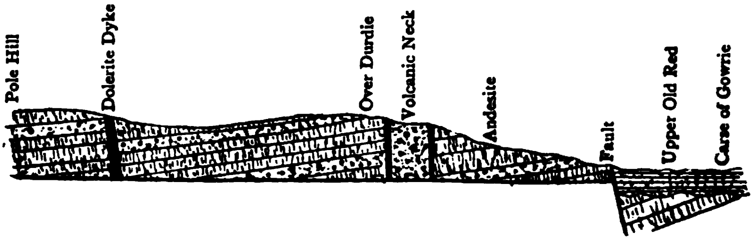
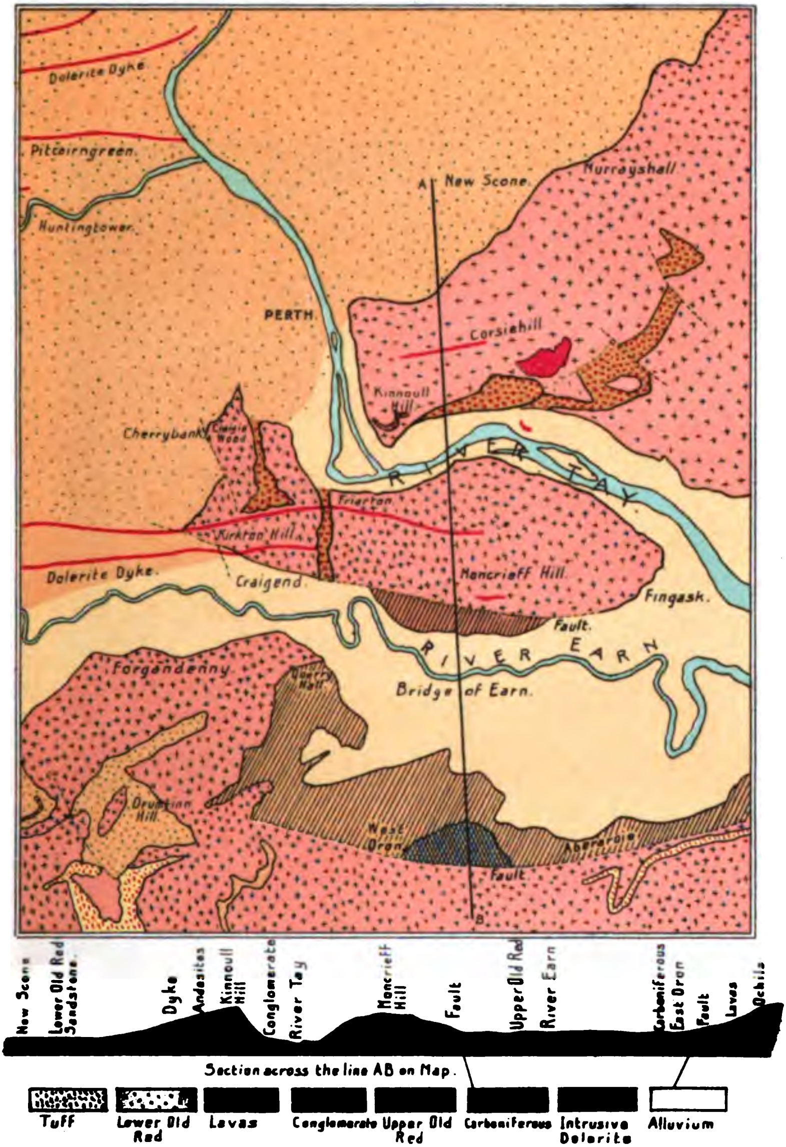


FIG. 32.—Section across the Sidlaws near Kilspindie showing volcanic neck at Over Durdie.

Perhaps the most interesting feature in the section just described is the volcanic neck which rises through the andesites at Over Durdie (see Fig. 32). This neck has an oval form, one of the diameters being 630 yards and the other 350 yards across. It is filled with a pinkish granular tuff, containing volcanic lapilli and blocks of andesite.

A third section will now be described for the purpose of showing the structure of the Ochils between Dunning and the Crook of Devon. Between Dunning and Auchterarder, and at the north end of the section, the volcanic rocks are seen to pass below the sedimentary rocks of Old Red Sandstone age. A fine section, showing both the andesites and tuffs, is seen in the Dunning Burn. Alternating with the tuffs are beds of conglomerate and sandstone, which dip towards the north-west, the whole group passing below the overlying sedimentary series, which covers the whole of Strath Earn. Further to the west, at Craig Rossie, near Auchterarder, there occur a series of lava flows, whose petrological characters we have just described. They were mapped as tuffs and breccias on the Geological Survey Map, but recent examination has shown that they are true lavas, and that their apparent stratification is due to the development of a fine flow-structure. These rocks rest upon andesites of the normal type, and they appear to represent the final outpouring in this part of the Ochil chain. A section across this area is given in Fig. 35. About a mile and a half to the south of Dunning, and near Quilts, an intrusive boss of norite penetrates the lavas and tuffs. This mass may probably represent the more deep-seated equivalents of the andesite lavas.



MAP AND SECTION SHOWING THE GEOLOGICAL STRUCTURE ROUND PERTH.

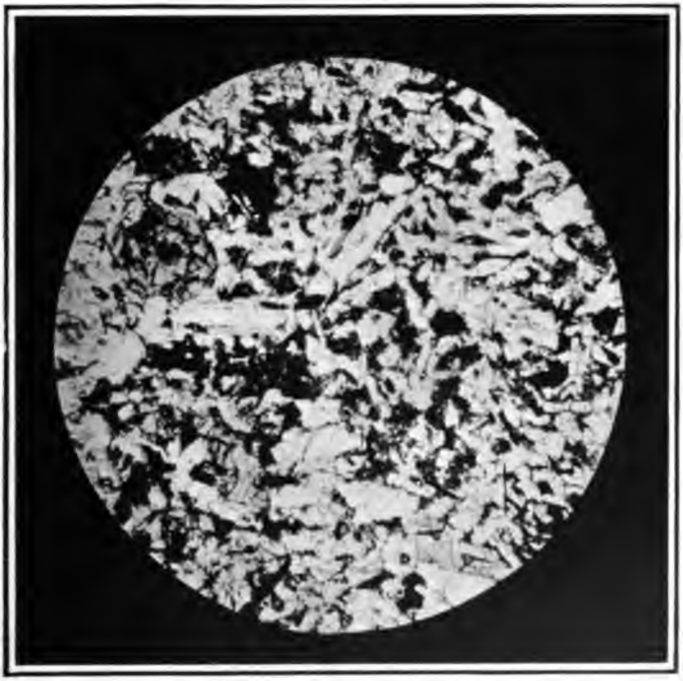


FIG. 33.—Compact Andesite. Kinnoull Hill, Perth. (Magnified 37 dias.)

Photo. by G. F. BATES, B.A., B.Sc.

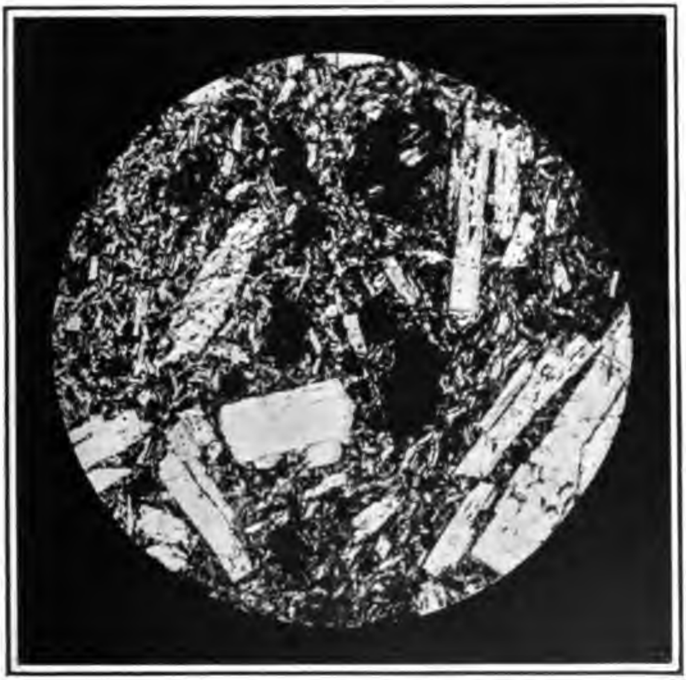


FIG. 34.—Andesite, showing porphyritic Felspars of first crop. Corsiehill, Perth. (Magnified 10 dias.)

Photo. by G. F. BATES, B.A., B.Sc.

Proceeding along the line of section as far south as Littlerig, we pass over a series of tuffs, agglomerates, and lavas in descending order, and forming the northern line of the volcanic anticline of the Ochils. At Littlerig, we not only cross the watershed at an elevation of about 1000 feet above sea level, but we also cross the crest of the anticline. The lava beds are seen to roll over and dip in the opposite direction until they reach the Crook of Devon. An inspection of the section given in Fig. 35 will show that the lavas of the Ochils rest upon a thick series of coarse agglomerates, whose base, however, is nowhere seen. These agglomerates and tuffs are well exposed in the neighbourhood of the Crook of Devon. At Fossaway they are seen to pass away below the andesites which form the main mass of Lendrick Hill. Three large bosses of intrusive felsite cut the anticline at Mellock Hill, Lendrick Hill, and White Hill. To the north of Saline, a powerful fault

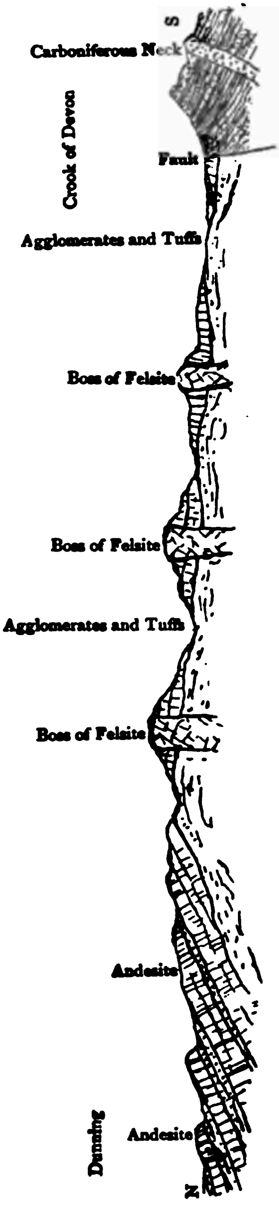


FIG. 35.—Section across the Ochils from Dunning to the Crook of Devon.

brings the Lower Carboniferous series, with the Hurlet Limestone, against the volcanic rocks of the Ochils.

That many of these lava flows were of a subaqueous character seems to be borne out by the fact, that they are intercalated between beds of sandstone and conglomerate, which appear to die out as they are traced away from the centre of discharge. Here and there, these lavas built up volcanic banks or hills, which rose along the margin of the ancient sea. From these volcanic foci were poured out thick beds of lava, some parts of which, at least, were under water. The periods of activity varied in duration and intensity. Sometimes sheet after sheet would be poured, one on the top of the other, without intermission. Then a period of comparative quiescence would intervene, and sufficient time would elapse for tolerably thick deposits of sand and gravel to be laid quietly down on the bed of the lagoon or sea. Again the subterranean forces gathered head, and a vast shower of dust and stones was shot into the air by the bursting open again of the choked-up volcano or volcanoes. This loose material was scattered all around, and fell on the beds of sand and gravel, the dust forming the beds of tuff, and the coarser materials the beds of breccia. After the loose material had been blown out, streams of lava were again poured forth, obliterating the face of the land for many miles. In this manner the thick pile of rocks forming the Ochils was gradually accumulated.

Here and there throughout the Sidlaws and the Ochils, the vents or orifices from which these lava streams were ejected, can be seen. As has already been pointed out, the most active vents appear to have been situated in the vicinity of Stirling, but these have

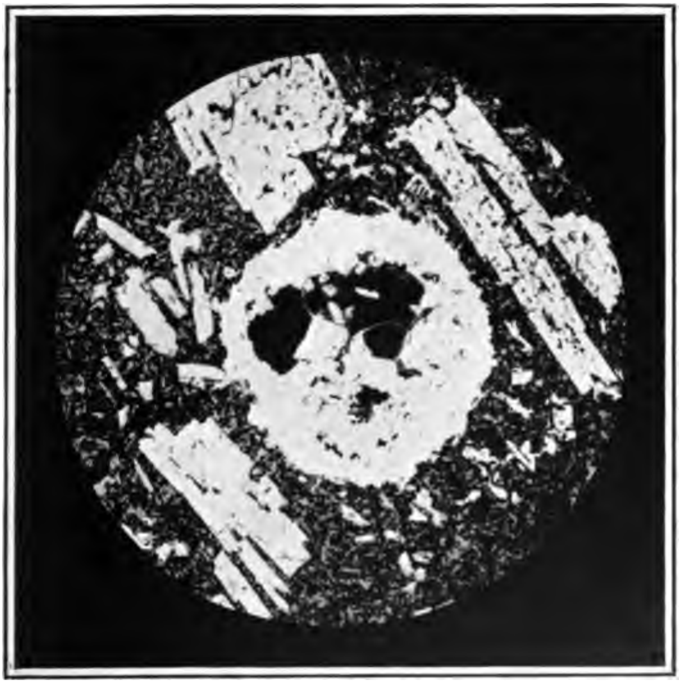


FIG. 36.—Vesicular Andesite. Kinnoull Hill, Perth. (Magnified 10 dias.)

Photo. by G. F. BATES, B.A., B.Sc.

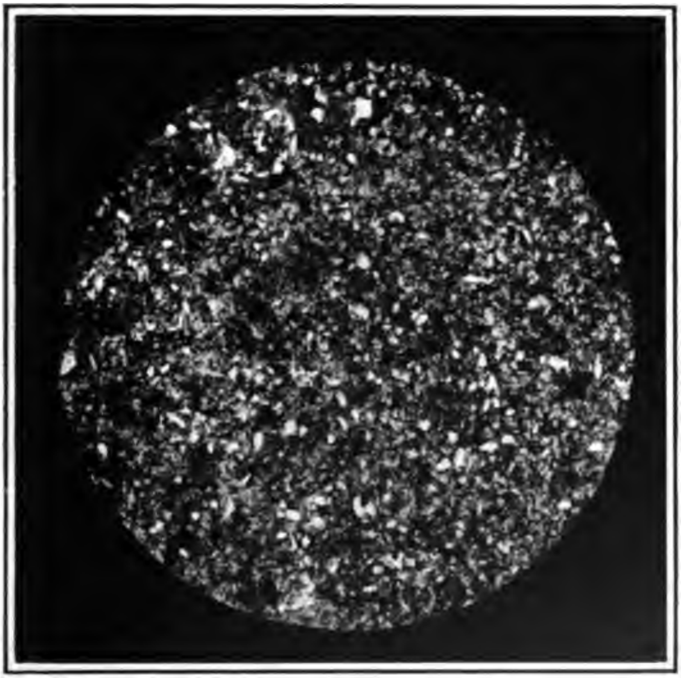


FIG. 37.—Volcanic Tuff. Kinnoull Hill, Perth. (Magnified 37 dias.)

Photo. by G. F. BATES, B.A., B.Sc.

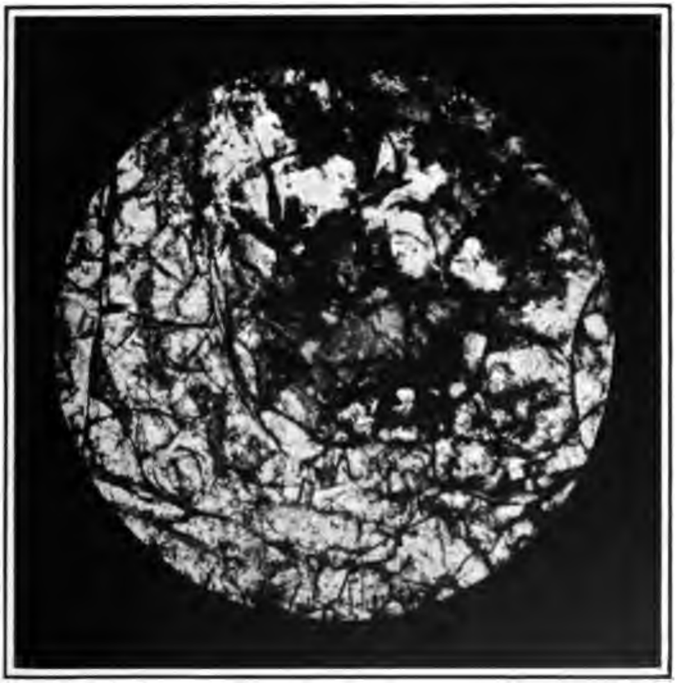


FIG. 38.—Volcanic Glass. Newburgh, Fife. (Magnified 40 dias.)

Photo. by JAS. B. CORR.

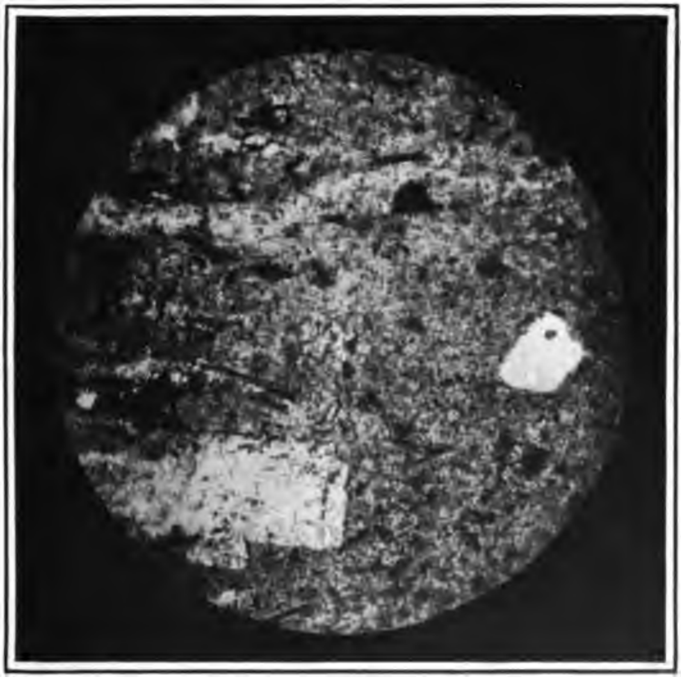


FIG. 39.—Rhyolite. Ochil Hills, Auchterarder. (Magnified 40 dias.)

Photo. by JAS. B. CORR.

been covered up by the younger Carboniferous formations. Such bosses of massive rock as those which lie between Dunning and the Crook of Devon, and which are seen to pierce the lava flows and agglomerate of the Ochils, most likely mark the sites of vents, which were active during Old Red Sandstone times. The numerous bosses in the vicinity of Dundee may also be considered as marking the deeper-seated portions of the old volcanic foci.

Necks which have been filled with fragmental volcanic materials are by no means so common in the Old Red Sandstone eruptions as they are in those of later Carboniferous times. Yet, occasionally, a solitary vent of this kind may be met with, the neck at Over Durdie, near Kilspindie in the Carse of Gowrie, being a good example of this type (see Fig. 32).

In the chapter dealing with the plutonic rocks of the Highlands, we referred to the possible connection that may exist between the bosses of granite, which penetrate the Highland schists, and the volcanic phenomena of Old Red Sandstone times. We saw that recent researches in the Lorne district have tended to confirm this connection between the plutonic and volcanic rocks in that region, so it is quite possible that some of the great bosses of later granites, which occur intruded into the crystalline-schists of the Highlands, may represent the deep-seated equivalents of the Old Red Sandstone lavas.

In concluding this chapter, we may briefly refer to the volcanic vent of Carboniferous age which occurs at East Grange, in the south-west corner of Fifeshire bordering upon the Firth of Forth. This neck pierces the strata which lie above the Index Limestone. The formation of the vent must have taken place after the deposition of the limestone. It measures 2000 feet from north to south, and 1500 feet from east to west. The interesting feature in this vent is that it is filled with non-volcanic debris. According to Dr. Peach, it contains dark, sandy, crumbling clays, full of fragments of sandstone, shale, and coal. The layers of this deposit have the same general dip as the strata which surround it. The sediments, which fill the neck, contain abundant calcareous nodules, which vary in size from an inch up to 18 feet in diameter. In the clays within the neck are found the remains of shells and crinoids, which flourished in the Carboniferous sea, into which the neck must have been opened.

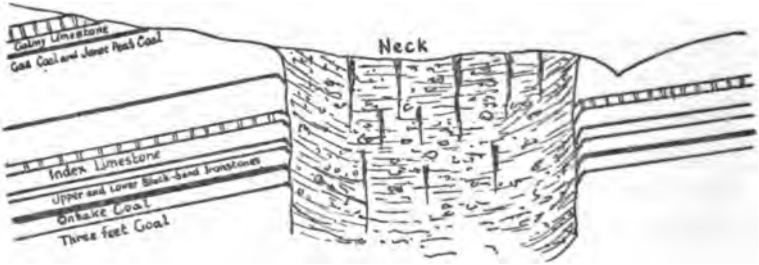

Calmy Limestone
Gas Coal and Janet Peat Coal
Neck
Index Limestone
Upper and Lower Black-band Ironstones
Onbake Coal
Three feet Coal

FIG. 40.—Section of the Carboniferous Volcanic Neck at East Grange.

This neck, then, appears to have opened upon the sea-floor, and does not seem to have emitted either lava or ashes, but only gave rise to gaseous explosions. In the course of time the crater walls were broken down by the sea, which entered the crater and formed a lagoon, in which the sediments, containing the organic remains just referred to, were accumulated. A section across this vent is given in Fig. 40. It has been drawn by Dr. Peach.

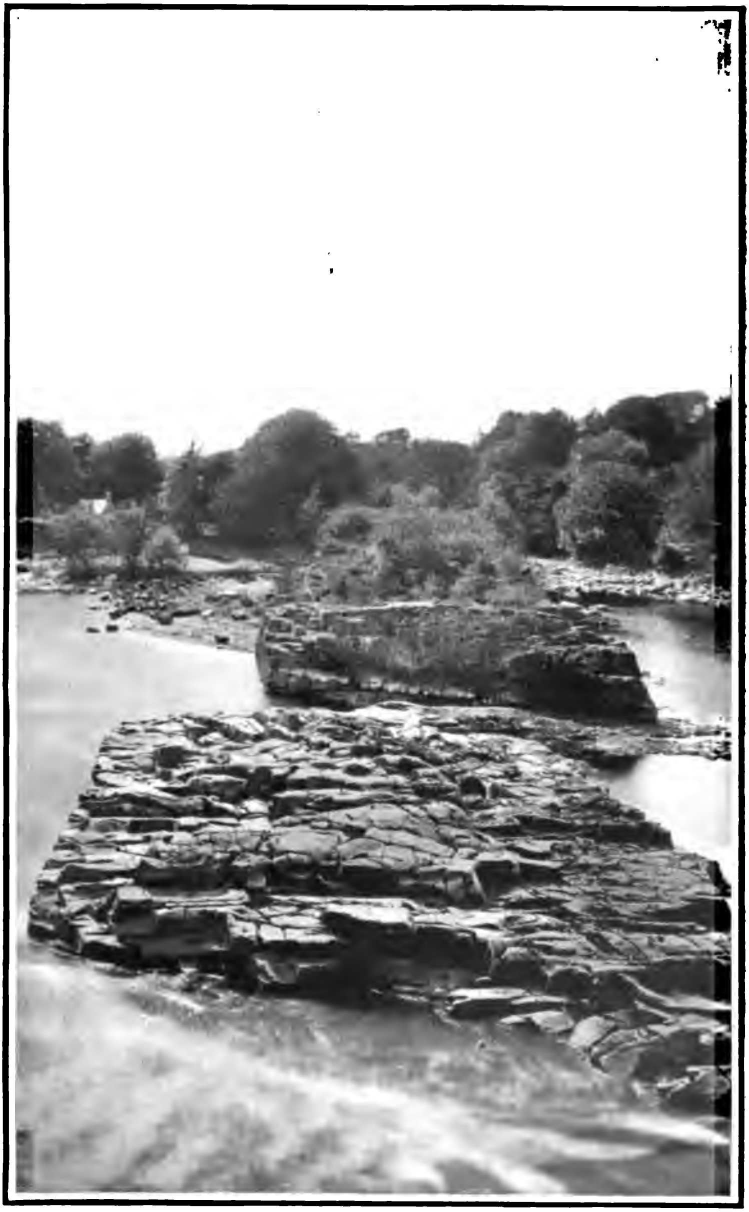


FIG. 41.—Linn of Campsie, showing Dolerite Dyke stretching across River Tay.

Photo. by R. KIDSTON, F.R.S., LL.D.

CHAPTER XII

THE DOLERITE DYKES

> The periods, which to our narrow apprehension and compared with our ephemeral existence, appear of incalculable duration, are in all probability but trifles in the calendar of Nature. It is geology that, above all other sciences, makes us acquainted with this important though humiliating fact. Every step we take in its pursuit forces us to make almost unlimited drafts upon antiquity. The leading idea which it presents in all our researches and which accompanies every observation, the sound which to the ear of the student of Nature seems continually echoed from every part of her works, is—Time!—Time!—Time!
>
> G. Poulett Scrope.

The numerous dolerite dykes which intersect all the solid rocks of the Grampians and Strathmore belong to a series which run across the whole of Scotland, and which are considered by some geologists to be of Tertiary age (Figs. 41 and 51). They have a general east and west trend, and can often be traced for long distances. In the case of some of the larger ones, they can be followed across the whole country. Thus, a well-known dyke enters Perthshire on the east side of Ben Lomond, from which point it has been traced eastwards across Loch Katrine, Ben Ledi, Loch Lubnaig, through Glen Artney to the north of Muthil, and then by Innerpeffray, Gask, and Dupplin, to Moncrieff Hill, south of Perth. Before entering Perthshire, this same dyke has also been traced across the Dumbartonshire Highlands and Cowal, almost to the shores of Loch Fyne, so that it may be said to pass across the whole country from shore to shore, extending to something like sixty miles. Another dyke of similar character runs parallel to the one just described at an average distance of about three-quarters of a mile to the north of it. This dyke has also been traced from Glen Artney to Moncrieff Hill. A view of one of these dykes, where it passes to the north of Muthill, is shown in Fig. 45. At this point it stands up with a wall-like appearance from amidst the more easily eroded Old Red Sandstone rocks.

A similar and equally persistent dyke crosses the Dunning Burn above Pitmeadow. From this point it has been traced at intervals through the hills north of the Braes of Doune and Uamh Mhor, and across the boundary fault, where it enters the Highland schists, near Callander. It then bends round and passes through Lochs Venachar, Ard, and Lomond. On the west side of Loch Lomond, it appears in the lofty ridge north-west of Luss, from which point it descends into Loch Long, crosses Glen Finart and Loch Eck, and disappears among the Cowal Hills. The total distance that this dyke can be traced is over sixty miles. Another, though shorter dyke, has been followed from Callander westwards to Doune and Dunblane, at which point it enters the Ochil Hills.

In Breadalbane, Perthshire, two large dykes have been traced for considerable distances. One of these

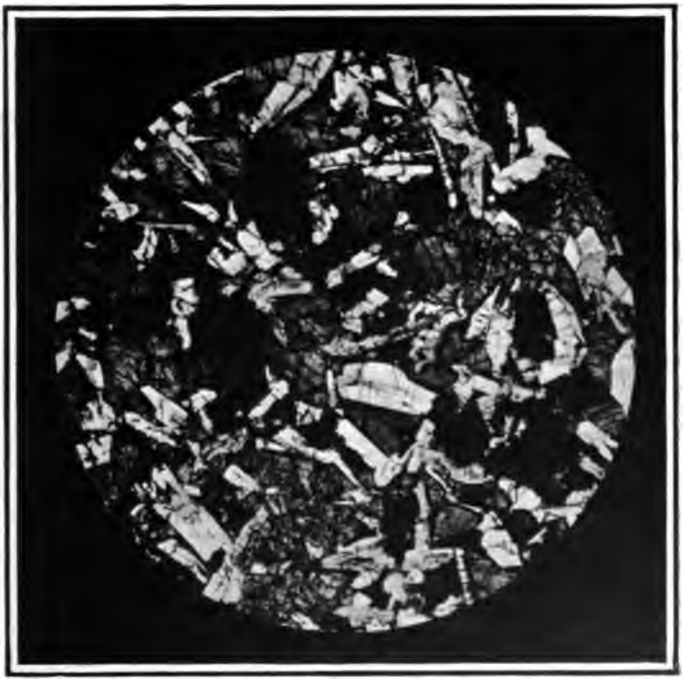


FIG. 42. —Dolerite. Centre of Dyke, Corsiehill Quarry, Perth.
(Magnified 12 dias.)

Photo. by G. F. BATES, B.A., B.Sc.

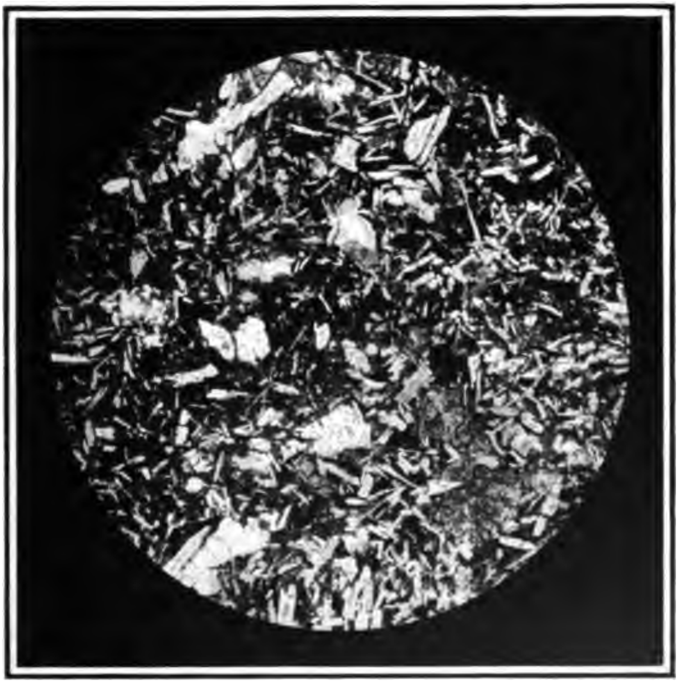


FIG. 43.—Dolerite. Margin of Dyke, Corsiehill Quarry, Perth.
(Magnified 12 dias.)

Photo. by G. F. BATES, B.A., B.Sc.

extends from Tyndrum along the ridge to the north of Glen Dochart by Killin and by the north side of Loch Tay. It crosses the loch near Lawers, and strikes eastwards down Glen Quaich, terminating to the north of Loch Freuchie. The other runs in a roughly parallel direction down Glen Dochart, along the south side of Loch Tay as far as Ardeonaig, and is probably the same dyke that has been traced, with interruptions, in the direction of Logiealmond.

Numerous examples of these dykes are exposed in the bed of the Tay or on its immediate banks. A small dyke crosses the river at Birnam about half a mile below Dunkeld Bridge. Another occurs at Broadgreen about a mile below Cargill. This dyke deflects the course of the river for about half a mile, the stream being compelled to run parallel with the dyke for that distance before it can effect a passage through it.

At the Linn of Campsie, near Stanley, two dykes intersect, one coming from the north-east, and the other from the east. They merge into each other, and appear to cross the river as one dyke, the point of contact being on the Stobhall side just at the edge of the water. This dyke is shown in Fig. 41.

Still further down the river, the Thistlebridge dyke crosses about a mile below Stanley (Fig. 44). This dyke is a very conspicuous object in the landscape, both in the river, where it is exposed at intervals above the surface of the water, and also on both the banks, where it stands out in bold wall-like masses.

Two smaller dykes may be observed in the bed of the river a few hundred yards below Thistlebridge. At Stormontfield and Waukmill, two other dykes cross the Tay. These are not so conspicuous in the river itself as those further up, but they are exposed on both banks, not many yards from the river. They run in an almost parallel direction as far west as the Almond Valley, where the latter is exposed at the Brig of Dalcrue. A photograph showing the dyke at this point is given in Fig. 1, vol. i.

About a mile and a half above the mouth of the Almond, though not exposed at the Tay, there occurs a dyke, which has been traced eastwards by Cromwell Park, Pitcairngreen, and Redgorton Church. In the immediate neighbourhood of Perth a dyke has been worked for a long time at Corsie Hill, where it is seen to penetrate the interbedded andesites of Lower Old Red Sandstone age. Another dyke penetrates the older volcanic rocks at Pitroddie and Kilspindie.

Perhaps the most striking feature of these dolerite dykes is the remarkable straightness of their sides. In many instances they are seen to rise from the surrounding rocks like a wall of masonry, presenting sharp and well-defined sides. This feature is, of course, best seen where the dyke has intruded among softer rocks than itself, as here the latter have been more readily worn away. In some cases the sides of the dyke are more irregular, but, as a rule, they present an almost uniform width over long distances. It seems most likely that these dykes have been formed in vertical or highly-inclined fissures, that have been opened in the crust of the earth, and into which liquid or plastic rock has welled upwards from the interior.

We have already referred to the remarkably persistent rectilinear course of many of these dykes, and it is hardly necessary that more should be said upon

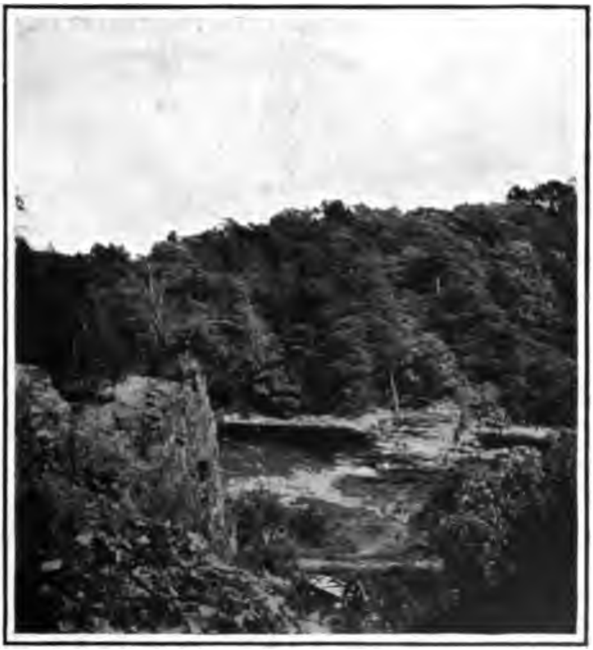


FIG. 44.—Dolerite Dyke at Thistlebridge, on the Tay, below Stanley.

Photo. by H. COATES.

this point, as a reference to the coloured sketch map at the end of volume i. will make this quite clear. The longest of the Perthshire dykes is that which has been traced from the head of Loch Goil eastwards across Ben Lomond, where it enters Perthshire. From this point it stretches across the whole of the county, apparently terminating in Moncrieff Hill. Still further to the east, and beyond Newburgh, what appears to be a continuation of this dyke runs through the Ochils as far as Norman's Law. If the latter portion be included, the total length of this dyke must be over seventy miles. To the south of the very long dyke just described, there occurs another very long one, which has been traced from the Highlands of Dumbartonshire, by Callander, to Auchterarder. This dyke has a length of forty-seven miles, with an average width of over a hundred feet.

From the Highlands of Dumbartonshire, to the neighbourhood of Aberfoyle, the former of the two dykes above referred to has an uninterrupted rectilinear north-west course. To the north of Aberfoyle it bends towards the north, which trend is kept till it reaches the Kelty Water, from which point it strikes due east as far as Auchterarder. To the north of Aberfoyle it cuts across the great lateral wrench, known as the Loch Tay fault, and in the neighbourhood of the Kelty Water it intersects the boundary fault.

Besides these large and persistent dykes, which can be traced for long distances, there occur other smaller dykes, which, as a rule, cannot be traced for any great length. One of these smaller dykes crosses the Tay about two hundred yards below the Thistlebridge dyke. It can be seen in the bed of the river, but cannot be traced further than the immediate banks; it is only six feet wide. About fifty yards further down the river, a similar dyke can be seen, which is eight feet wide.

As a rule, there is little or no evidence of any bifurcation in the great dykes which cross Perthshire. One instance, however, has been noted by Sir A. Geikie as occurring in one of the two great parallel dykes which have been described. This takes place where the dyke passes across Glen Artney, near the foot of the valley. The northern limb of the bifurcation extends for about two miles, and then dies out. The southern limb, which continues eastwards as the main dyke, also sends off a small shoot to the north-east.

Owing to the general parallelism in the trend of the dykes, there are but few evidences of intersection between two dykes. That of the dyke at Campsie Linn has been referred to, and may be described in more detail. The point of contact is on the east side of the river, and takes place near the edge of the water. The longer dyke runs due east and west, and has been followed from the Linn of Campsie to the east of Wolfhill, a distance of four miles, where the dyke crosses the main road leading to the Bridge of Isla. A quarry has been opened, and a fine exposure, both of the dolerite and the sandstone into which it has intruded, may be seen at this locality. For the distance of a quarter of a mile above the Linn of Campsie the River Tay is compelled to take a westerly course, and this is seen to be due to the presence of a second dyke, which intersects the one already described at the Linn. This dyke has a

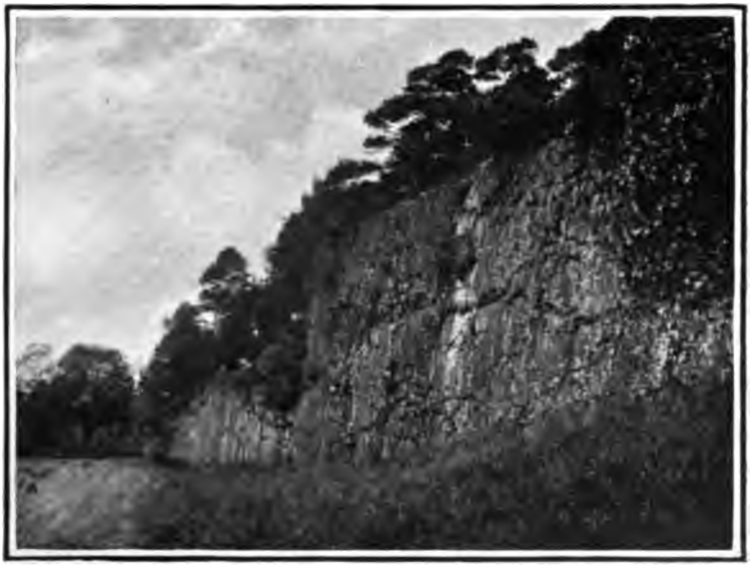


FIG. 45.—Dolerite Dyke, between Crieff and Muthill.

Photo. by WM. REID.

north-easterly trend, and has been traced for a distance of about two miles, forming the ridge upon which Stobhall Castle is built.

Another striking feature of these dykes is the manner in which they cut across even the largest and most important faults without showing any signs of alteration or deflection. Nor does the geological structure of the ground, or the nature of the rock which they traverse, make any difference in this respect. Thus, the two great dykes, which we have just described as crossing the whole of the county, cut the boundary fault in Glen Artney, between Callander and Comrie, without being affected by the fault. Later on, we shall see that they cross hill and valley, running up to the summit of the highest peaks or descending to the deepest valleys, but never showing any evidence of having reached the surface. It seems highly improbable that such a large number of dykes should have been erupted without some of them reaching the surface, but if they did, all evidence of such has now been removed by denudation.

In Perthshire, these dykes are seen to cut indifferently both the Crystalline-schists of the Highlands and the much younger Old Red Sandstone rocks. In the west of Scotland and the north of England they are seen to penetrate rocks of Liassic age.

The well-known dyke in the north of England, known as the Cockfield dyke, has been traced from Cockfield Fell, in Durham, to near the coast at Whitby, a distance of nearly sixty miles. It may be seen at Maybecks on Smeaton High Moor, Silhowe Cross, Grosmont, Castleton, Rye-hill and Nunthorpe in the Vale of Cleveland. In its course through Yorkshire, it is known to penetrate the New Red Sandstone, the Lias, and Lower Oolite formations, thus demonstrating that it is younger than any of these formations. All these dykes evidently belong to the one great series, which appears to emanate from the volcanic plateau of the West of Scotland. The latest formation which the Cleveland dyke is seen to intersect is that of the Oolitic Sandstones of the Yorkshire moors, and it must be later than these, or of post-Jurassic age.

In width these dykes vary, from a few feet, up to a hundred feet, as in the case of the dyke seen at Callander and Auchterarder. They also vary considerably in their internal structure. Thus, some are almost entirely massive, save for a slight irregular jointing, while others show a more or less perfectly-developed columnar structure. The columns usually strike off at right angles from the sides of the walls, some of them going completely across the dyke, while others appear to terminate before reaching the centre, in which there is a non-columnar part. When the sides of these dykes have been exposed by the removal of the surrounding rock, they usually present a polygonal network of joints, formed by the ends of the columns (see Figs. 46 and 51).

Besides these conspicuous joints which stand at right angles to the planes of cooling, another set, which are arranged parallel to the walls of the dyke, are frequently to be met with. Like the former set, they are closest towards the margin, and may be entirely absent towards the centre of the dyke. They occasionally occur in such large numbers towards the

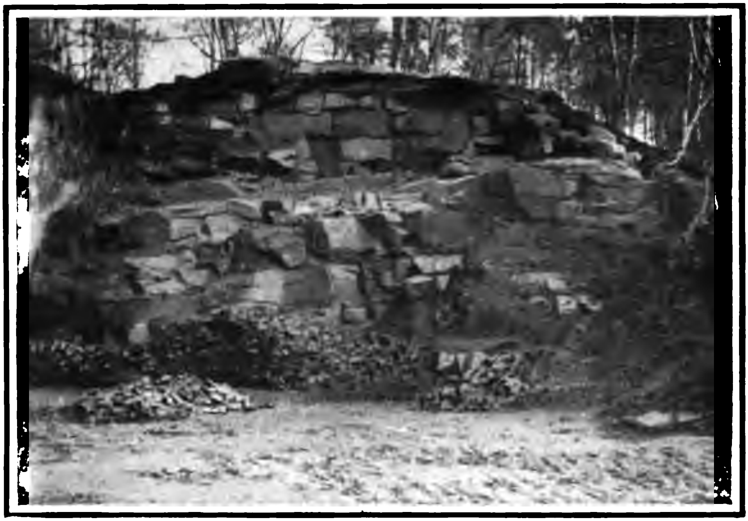


FIG. 46.—Quarry in Campsie Linn Dyke, near Stobhall.

Photo. by G. F. BATES, B.A., B.SC.

edges of the dyke as to give the rock a flag-like structure.

Another structural characteristic of these dykes is, that as a rule the edges, or outer parts, are much less coarsely crystalline than the centre of the dyke. This is accounted for by the fact, that where the dyke came in contact with the walls of the fissure it would cool much more rapidly than it would towards its centre, where the process of crystallization would be much slower and much more perfect. In some cases a selvage of tachylyte marks the rapidly chilled edge of the dyke.

The rocks in contact with these dykes usually show more or less evidence of having been subjected to contact metamorphism, the grains of sand in sandstone having been fused into each other so as to form a sort of quartzite. This indurated character is very well shown where the dykes have cut through beds of conglomerate and grit. Where they cut the Highland schists, the schists give evidence of contact metamorphism, which is quite distinct from their much earlier dynamic metamorphism. This can be well seen in the dyke which pierces the Loch Tay Limestone east of Killin.

As has already been seen, some of the dykes form wall-like rocky scars (see Fig. 45), this being due to their ability to resist the weathering agents more strongly than the adjacent rocks. Others form hollows or slacks, in which case they have evidently a less resisting power than the rocks with which they are in contact. It is not quite clear why this should be, but it seems highly probable that it is in some way connected with the grain of the rock. So far as our observations have gone, it seems that the coarser-grained dykes are more easily eroded than the finer-grained dykes, the former tending to make hollows, while the latter make ridges.

A more or less well-developed vesicular structure can be seen in some of the dykes, these vesicular areas being generally arranged with their margins parallel to the sides of the dyke, and where a number of such areas exist in the same dyke, they are always parallel to each other and to the sides of the dyke. When an amygdaloidal structure occurs in the centre of the dyke, it indicates that this was the last portion of the dyke to consolidate, and shows that as the outer portion of the dyke cooled, a contraction in the bulk of the dyke took place, which resulted in a lowering of the pressure towards the centre, and so allowed the vesicles to be formed. Calcite, quartz, agate, and zeolites are the most common minerals to be found filling these vesicles in the dykes.

It was formerly supposed that the amygdaloidal structure, seen in igneous rocks, was a characteristic feature of these rocks that have reached the surface and flowed out as lavas, and that this structure served to distinguish them from those which had been consolidated under considerable pressure in the interior of the earth. The fact that many of these dykes show a well-developed vesicular structure does not, of course, confirm this view. Nevertheless they have certain characteristic features, which help to differentiate them from lavas which have been poured out at the surface. Thus, the vesicles have a tendency to assume more rounded or spherical shapes than those seen in lava flows, the latter being usually drawn out in directions

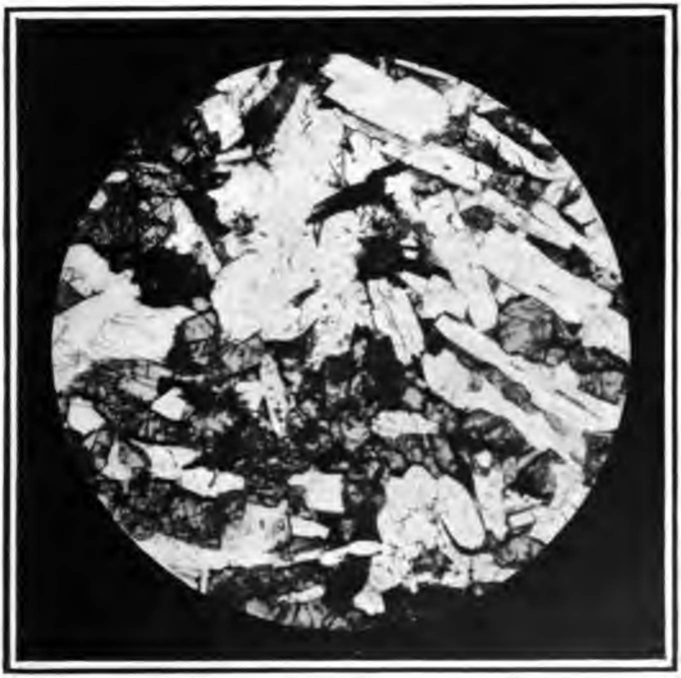


FIG. 47.—Dolerite. Pitroddie. (Magnified 12 dias.)

Photo. by G. F. BATES, B.A., B.Sc.

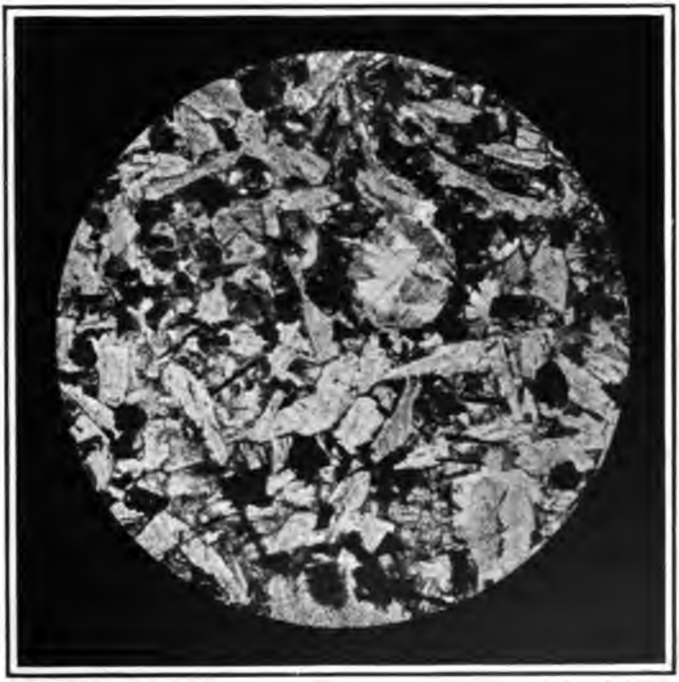


FIG. 48.—Dolerite. Centre of Dyke, Campsie Linn.
(Magnified 12 dias.)

Photo. by G. F. BATES, B.A., B.Sc.

parallel to the line of flow. Further, as we have observed, the vesicles are not, as a rule, distributed through the whole width of the dyke, but are arranged in bands or lines parallel to the sides of the dyke, and are best developed towards the centre of the intrusion.

Occasionally, a dyke is seen to enclose fragments of the rock into which it has been intruded, and where this has taken place, the inclusions of foreign rocks are seen to be arranged with the longer axes of the fragments parallel to the sides of the dykes.

As a rule, these dykes assume a vertical, or nearly vertical position, but occasionally they are seen to hade at considerable angles. This feature is well shown in the dyke exposed at Catscraig Quarry, about half-way between Blairgowrie and Craighall. This dyke has been intruded into the basal conglomerate of the Lower Old Red Sandstone, and is inclined at an angle of about 20° to the perpendicular. The proximity of the dyke to the great boundary fault may have had something to do with the departure of the dyke from the usual vertical position.

These dykes consist of dolerite, which exhibits a pretty uniform character throughout all the intrusion. The rock is usually of a dark grey or black colour in fresh hand specimens. When the rock has been subjected to meteoric influences it exhibits a rusty-like appearance, and also, sometimes, a characteristic spherical exfoliation. This is well seen in the Thistlebridge dyke, on the Tay below Stanley. The constituent minerals are a plagioclase felspar and augite. The most common accessory minerals are magnetite and apatite. The plagioclase felspar, which appears in some cases to be labradorite, and in others, anorthite, occurs in long, lath-shaped crystals, which exhibit the characteristic polysynthetic twinning of the triclinic felspars. Seen in thin sections between crossed nicols, it appears as a parallel striation, consisting of light and dark bands, due to the simultaneous extinction of alternate lamellae. As a rule, this striation is parallel to the brachypinacoid. This constitutes the albite type of twinning. A second series of twin-lamellae sometimes crosses the former at right angles, constituting the pericline type of twinning. If a hand specimen of some of the coarser dykes be examined with a lens, the lath-shaped forms of the felspars, constituting the ground-mass, can be distinguished. But besides these small crystals of the ground-mass, larger, and more stoutly-developed crystals are to be met with in some of the dykes, giving the rock a porphyritic character. These phenocrysts are often seen to be cracked and penetrated by the ground-mass. They are evidently the products of an early consolidation. They may occur equally abundantly at the edges as in the centre of the dyke, from which it may be inferred that they were in existence when the fluid rock was injected into the fissure. The smaller felspars of the ground-mass evidently represent a later phase in the process of crystallization. They vary in size and perfection of development, according to their position in the dyke; those found near the centre, where the cooling has been slowest, being largest, and best developed; those near the edges, where the cooling has been more rapid, being smaller and less perfectly formed.

The pyroxenic constituent is invariably black or common augite, which presents a brownish colour

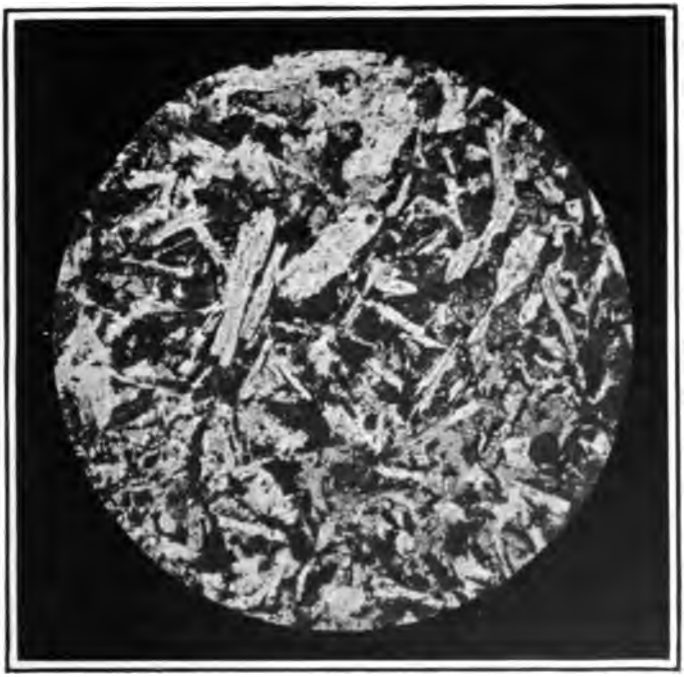


FIG. 49.—Dolerite. Margin of Dyke, Campsie Linn.
(Magnified 37 dias.)

Photo. by G. F. BATES, B.A., B.Sc.

when seen in thin sections. Magnetite and apatite are usually present as accessory minerals, the former occurring in grains and idiomorphic crystals, the latter in long, prism-shaped crystals, which under crossed nicols give straight extinction. The principal secondary minerals, due to decomposition are, ilmenite or titaniferous iron ore, iron pyrites, and calcite.

Structurally, these dykes are either porphyritic, as has already been described, or they are ophitic or sub-ophitic—the last two being the more common. When the rock presents an ophitic structure, the felspar appears to have crystallized out at a slightly earlier period than the augite, and the lath-shaped crystals of felspar are seen to penetrate the augite, the latter playing the rôle of ground-mass. The former existence of a glassy base can be detected in many of the dolerites, but, as a rule, this base, through subjection to meteoric influence, has become devitrified. The presence of a glassy selvage can be seen in some of the dykes. This is well seen in the large dyke which crosses the whole of Perthshire, and which is exposed in a large quarry near the Caledonian Railway Station at Auchterarder. Towards the centre, this dyke exhibits a coarsely crystalline ophitic structure, the rock being an olivine-dolerite. The olivine crystals, which are not numerous, have been converted into serpentine. Traced outwards towards the margin, the rock becomes much finer in the grain, and at the very edge of the dyke passes into a glassy condition, which has a thickness of 1.5 cm. Mr. Seymour, of the Geological Survey, describes this glassy selvage as follows: "In a slice taken from the actual wall of the dyke, and showing the intrusive rock in contact with the sandstone, the dolerite, owing to its being rapidly cooled in contact with the sandstone, is composed of tachylyte. This glass is now palagonitic, and in it porphyritic calcified felspars are noticeable. The glassy character of the selvage decreases rapidly till, at a distance of 1.5 cm. from the line of contact, it is distinctly micro-crystalline. There does not appear to have been any injection of the tachylyte into the sandstone, the only noticeable result being the optical strain structure set up in the component quartz-grains, and due, probably, to the baking effect of the igneous rock. It is also rather stained with yellowish iron oxides."[1]

Fig. 47 is from a photograph of a thin section of dolerite, taken from the Pitroddie dyke. It shows long, lath-shaped crystals of plagioclase felspar, which are clear and colourless. These are set in a groundmass of brownish augite, the shapes of the augite crystals being largely determined by the already crystallized felspar. The opaque mineral is magnetite. This brings out the structure of the rock more clearly, and also shows the complex polysynthetic twinning of the felspars. Figs. 42 and 43 show a similar rock from the dyke which cuts the interbedded andesites at Corsiehill, near Perth. Figs. 42 and 43 when compared, show very well the difference in texture, which exists between the dolerite, as seen at the margin of the dyke, and in the centre. In Fig. 43, taken from the margin, the crystals of plagioclase felspar are comparatively small, while in Fig. 42, which it taken from the centre of the

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[1] *Memoirs of the Geological Survey of Scotland.* "Geology of East Fife," p. 404.

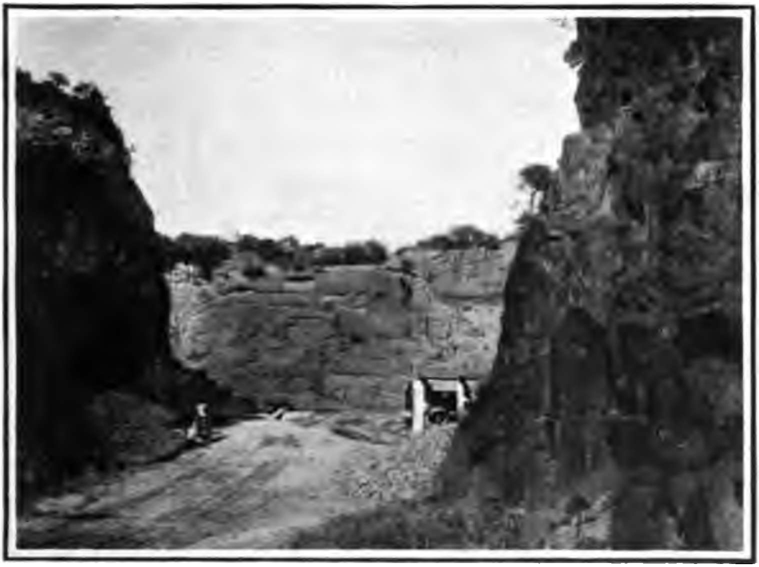

FIG. 50.—Dolerite Dyke, Corsiehill Quarry, near Perth.

Photo. by WM. ELLISON.

dyke, the felspars are much larger and more stoutly developed. In both cases the magnification is the same.

Beginning in the north of England, we find such solitary dykes as the Cockfield dyke already mentioned. Traced northwards into Scotland, they are seen gradually to increase in numbers, until they reach their maximum development in the vicinity of the great Tertiary volcanic plateaux of Antrim, Mull, and Skye. Sir A. Geikie thinks that it seems almost certain that this system of dykes is associated with the outpourings of lava, which took place during that period in geological time.

This plateau of Tertiary volcanic rocks appears to have extended northwards through the Faroe Islands, and Iceland into Greenland. The period, at which this extensive outpouring of lava took place, is indicated by the remains of early Tertiary plants, that have been found among the fine tuffs and other deposits intercalated between the lava flows.

According to Professor Judd, we have in the islands of Skye, Mull, Rum, and St. Kilda, the denuded stumps of great volcanoes, that of the Island of Mull being on a grander scale than the modern volcanoes of Italy. The sequence of events which took place during this period of volcanic activity was, according to Professor Judd, as follows: First there was a discharge of acid lavas and ashes, which consolidated in the deep-seated portions of the volcanoes as granite; this was followed by the eruption of the lavas of the basaltic plateau, which he supposes to have their deeper-seated equivalents in the great masses of gabbro and dolerite; and finally, a number of sporadic cones made their appearance, emitting comparatively small flows of lava.

The views advanced by Sir Archibald Geikie differ in many important points from those of Professor Judd. Thus, the former does not consider that there is any evidence to support the previous existence of the great volcanic cones, described by Professor Judd, but believes that the eruptions, which formed the basaltic plateau, took place from fissures or rents in the earth's crust, along the lines of which small cones may have established themselves. Subsequent to the protrusion of the lavas, forming the basaltic plateau, they were pierced by great intrusions of gabbro, which produced a certain amount of metamorphism, where they came in contact with the lavas. Finally, great masses of granophyre and other acid materials were injected into the basic rocks.

We have briefly indicated the views advanced by Sir A. Geikie and Professor Judd, regarding the nature and sequence of the events, which took place during the activity of these old Tertiary volcanoes in the Western Islands of Scotland, but it can only be regarded as having an indirect bearing upon the geological history of our region; for, though it were proved beyond the shadow of a doubt that the great north-west dykes seen in this area are of Tertiary age, and that they emanate from the volcanic plateau of the Inner Hebrides, we have no clear evidence that they ever reached the surface.

Professor Judd thinks that there is no evidence to support the sweeping generalization made by Sir A. Geikie, in which he seeks to bring all these dykes, or even the great majority of them, into the Tertiary

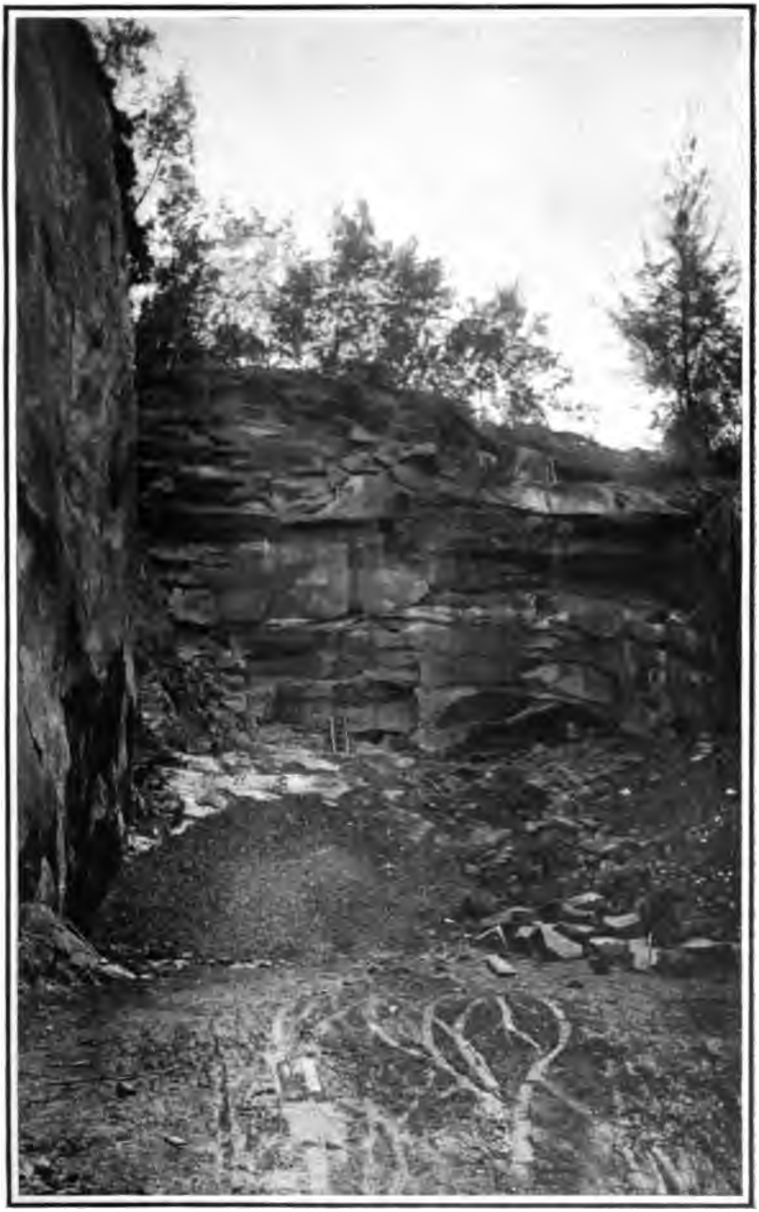

FIG. 51.—Dolerite Dyke, Laggan Quarry, Glen Lednock, near Comrie.

Photo. by WM. ELLISON.

period. He admits that many of the basalt dykes, which occur in the Western Islands of Scotland and Antrim, and which radiate from the great centres of eruption, are of Tertiary age, but he cannot see any reason for including in the same category all the dykes, which occur in the Central Valley of Scotland, Fifeshire, or Forfarshire, as the available field evidence is only sufficient to show that, while some are later than Ordovician times, others are younger than Old Red Sandstone or Carboniferous times. In support of this view he refers to the conclusion that Mr. Allport had arrived at regarding the remarkably fresh condition of some of the basic rocks of Carboniferous age, found in central Scotland, and also to the striking resemblance between many of these dyke rocks and the lavas just mentioned. Professor Judd admits that a few of the dykes in the north of England, such as the Cockfield dyke, which has been referred to, and also the Eskdalemuir dyke in the south of Scotland, may be of Tertiary age. The Cockfield dyke is known to intersect Mesozoic strata, and has a characteristic mineralogical composition (augite-andesite or "tholeiite" of Rosenbusch), which differentiates it from other dykes in the district, which he regards as being much older. The Eskdalemuir dyke may be of the same age as the Cockfield dyke, as they have a similarity in mineralogical composition. In summing up Professor Judd says: "I fail to find any evidence, based either on the petrological character of the dykes, the directions in which they run, or any other peculiarities, that can safely discriminate between the Newer Palaeozoic dykes and those which are of Tertiary age. Still less can I find any evidence for the confident assertion that the great majority of the basic dykes over such a wide area must all be of Tertiary age."

In the Cowal region, Mr. C. T. Clough has observed that there are two systems of dykes, the one being an east and west system, which appears to be the older of the two, and which he supposes to be of late Carboniferous age, and probably contemporaneous with the dolerite sills or sheets so abundant in the Carboniferous rocks of the Midland Valley of Scotland. The other set, or the north-west dykes, are, he believes, of Tertiary age, since they are seen, in Mull, to cut the plateau of Tertiary lavas. If this view regarding the age of these dykes be correct, then there must have been an enormous interval of time between the eruption of the two sets of dykes. Judging from the trend of the principal dykes seen in Perthshire, they would appear to belong to the older set of dykes.

The vast amount of denudation that has taken place since the intrusion of these dykes is evident from the manner in which they run from the deepest valleys to the highest mountains without showing any evidence of having outflowed at the surface. Thus, the dyke which crosses Ben Lomond, and to which reference has already been made on several occasions, descends almost from the summit of Ben Vorlich on the east, passes through Loch Lomond and ascends Ben Lomond to an altitude of over 2000 feet. The difference between its highest level in Ben Vorlich and its lowest in Loch Lomond has been estimated at over 3000 feet. The great hollow of Loch Lomond could not have existed when the dyke was intruded, or it would have overflowed and filled the hollow.

Consequently over 3000 feet of rock must have been removed from the surface, since the intrusion of this dyke. If this dyke be of Tertiary age, as maintained by Sir A. Geikie, then it follows that this thickness of rock has been removed from the surface of the country within a comparatively late period in geological time.

CHAPTER XIII

THE GLACIATION OF THE GRAMPIANS AND STRATHMORE

The glaciers creep
Like snakes that watch their prey, from their far fountains,
Slow rolling on; there, many a precipice,
Frost and the sun in scorn of mortal power
Have piled: dome, pyramid, and pinnacle,
A city of death, distinct with many a tower
And wall impregnable of beaming ice.

SHELLEY.

BOTH in the Grampians and in the great Valley of Strathmore there is abundant evidence of the former existence of glaciers during what is known as the great Ice Age. In fact, it would scarcely seem possible to select a more typical area for the study of the phenomena connected with this period in the geological history of Great Britain than that under consideration. An examination of all the evidence connected with the glaciation of this country goes to show that there were at least two great phases of this glaciation. The older or general glaciation of the country took place during the climax of the Ice Age, when the whole of this country must have been covered with a thick sheet of ice, comparable to that seen in Greenland at the

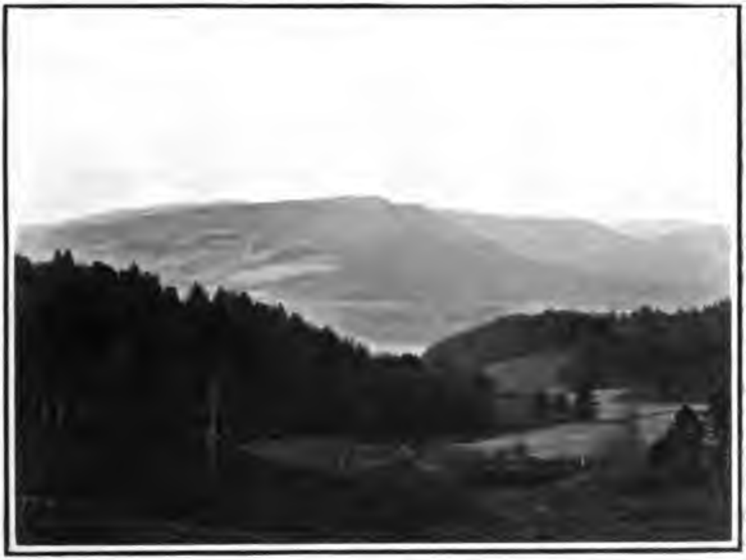

FIG. 52.—Kinnoull Hill, from Callerfountain.

Photo. by CHAS. KIRK.

present day. This sheet of ice appears to have pressed steadily outwards from the central Highlands in a general south-easterly direction, and wherever surfaces of rock are exposed they are invariably seen to be finely rounded, polished, and marked with a regular and persistent series of striations.

A careful examination of the striae shows that the movement of this great ice sheet, during the maximum period of cold, must have been quite independent of the existent valley systems; while the heights at which these striae have been observed show that the ice must have over-ridden even the most lofty mountains. According to Mr. James S. Grant Wilson, one of the most remarkable features connected with the glaciation of Perthshire is, that during the period of extreme cold the ice-shed did not coincide with the water-shed, but lay about twenty miles to the east of the present water-shed.[1]

In the district which lies between the head of Glen Lyon and Glen Lochay, and at an altitude varying from 2700 to 3000 feet, the striae point in a south-easterly direction. Further to the east, in the neighbourhood of Loch Tay, it is evident that when the great *mer de glace* covered the whole of Scotland it must have moved outwards in a similar south-easterly direction, for near the summit of Creag na Caillich, about three miles north of Killin, the striae are seen to point towards the south-south-east. On both sides of Loch Tay numerous striae may be observed upon the hill slopes, and an examination of these shows that the direction of the ice movement must have been E. 20° to 30° S. Upon the ridge which separates Glen Lyon and Loch Tummel there is evidence of a similar character; for, on the slopes of Schichallion, at an elevation of 3000 feet, the striae point E. 30° S., while on the hill slopes that surround Loch Tummel a similar direction of the glaciation can be seen. On Beinn a' Chuallaich, north of Kinloch Rannoch, a mountain rising to an elevation of 2925 feet, striae have been observed close to the summit of the mountain. Here, again, the trend is the same as in the localities already given. Still further to the east, Ben Vrackie, situated to the north of Pitlochry, has been glaciated to the very summit (see Fig. 56).

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[1] "A Bathymetrical Survey of the Chief Perthshire Lochs and their Relation to the Glaciation of that District," *The Scottish Geographical Magazine* for May, 1888.

In the south-western part of the district the evidence as to the direction of the movement of the ice-sheet is of a similar character. Thus, on Ben Vorlich and Stuc a' Chroin, which rise to over 3000 feet in height, striae have been found upon their summits, showing that the whole of the high ridge which lies between Loch Lubnaig and Loch Earn must have been over-ridden by the ice. Again, in the district that lies between Loch Katrine and Loch Lubnaig, Ben Ledi, Ben Vane, and Meall Cala have been over-ridden in a similar manner. Between Loch Katrine and Loch Lomond striae occur on the summit of Ben Venue at an altitude of 2386 feet. Abundant evidence of glacial striae may be seen upon the bare surfaces of schistose grit that form the slopes of Ben A'an and Ben Venue in the rocky defile that guards the outlet of Loch Katrine. Still further to the west, on Beinn Bhreac, Beinn Uaimhe, south of Loch Arklet, and Maol Mor, near the head of Loch Katrine, glacial striae may also be observed.

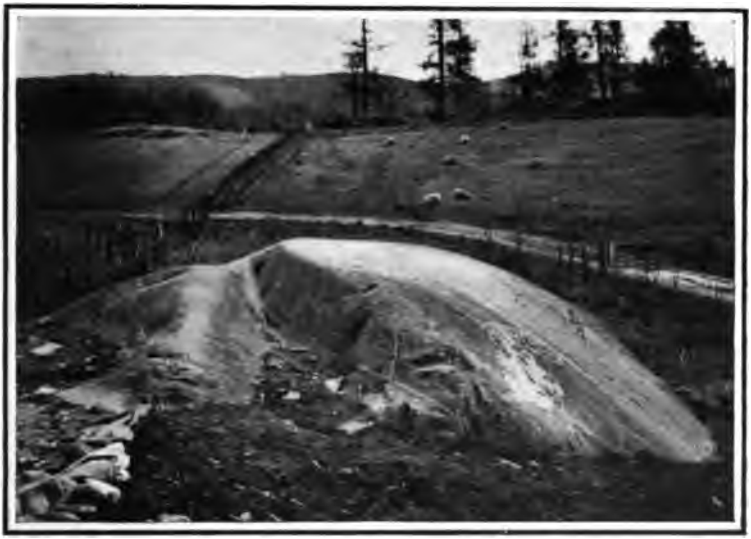

FIG. 53.—Roche Moutonnée, near Aberfoyle.

Photo. by A. S. REID, M.A., B.Sc.

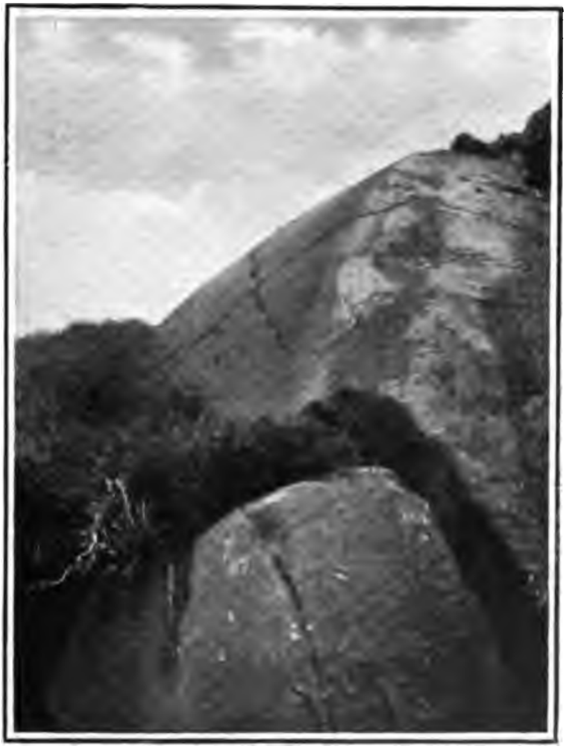

FIG. 54.—Roche Moutonnée in Glen Turret.

Photo. by D. M. GALL, B.Sc.

To the north and west of Loch Lomond, and in the Cowal district, the trend of the ice-sheet during the period of maximum glaciation appears, from the evidence derived from the glacial striae, to have been more towards the south and south-west.

From what has been said it will be seen that the general trend of the ice movement along the frontier Highlands has been from N.W. to S.E. When it reached the low ground of Strathmore it veered towards the east, and then swept right across the Ochil and Sidlaw Hills in a direction a little to the north of east (see Fig. 55).

All over the Grampians and the Valley of Strathmore are to be found boulders or erratics which have travelled far from their parent sources. That this dispersal of these boulders took place during the primary glaciation of the area seems highly probable, as the direction of their movement seems to be generally coincident with that of the ice-markings which have been described. Not only have these boulders been carried in many instances from the Grampians and spread over the plain of Strathmore, but they have also been carried over the highest cols in the Sidlaws and Ochils.

On the high ridge of ground which stretches from Loch Lubnaig to Loch Earn, formed of the Ben Ledi Grits, and which includes Beinn Each, Stuc a' Chroin, and Ben Vorlich, boulders of garnetiferous mica-schist, epidiorite, and hornblende-schist, all of which rocks are closely associated with the Loch Tay Limestone, have clearly been transported to their present positions from the lower ground to the north. On the slopes of Ben Ledi the boulder-clay contains blocks of hornblende-schist, which must have been carried from a considerable distance to the north of their present position. Within the catchment-basin of Loch Katrine there have been found boulders of the black-schist which accompanies the central Highland quartzite, but this rock has not been discovered *in situ* within the Loch Katrine basin. The great boss of diorite, or hornblende-granite, which covers such a large area in the Moor of Rannoch, has supplied boulders which have been dispersed over a very wide district. They are to be found in Glen Lyon, Strath Tummel, and Strath Tay, and have even been traced across the water-shed into Glen Almond. Everywhere in the long valley of Strath Fillan, Loch Tay, and Strath Tay, from Tyndrum to Ballinluig, and resting either directly upon the garnetiferous schists or enclosed in the boulder-clay, are to be found blocks of quartzite, black-schist, and Ben Lawers phyllite; and these must have been carried from the north, as the outcrops of these rocks all lie to the north of the garnetiferous schist upon which they are now seen to rest (see Figs. 57 to 62).

Towards the south-western end of the Grampians the direction of the ice movement is very clearly shown by the distribution of the boulders which have been derived from the intrusion of granite and diorite on Garabal Hill, between the heads of Loch Lomond and Loch Fyne. The granite boulders have streamed down Loch Lomond, Loch Long, Loch Goil, and Loch Fyne, and they have been distributed in large numbers all along the shores of the Firth of Clyde. From a consideration of all the evidence supplied by the glacial striae and the erratics, it seems that during the maximum period of cold the Grampians must have been buried under an ice-sheet at least 3000 feet in thickness.

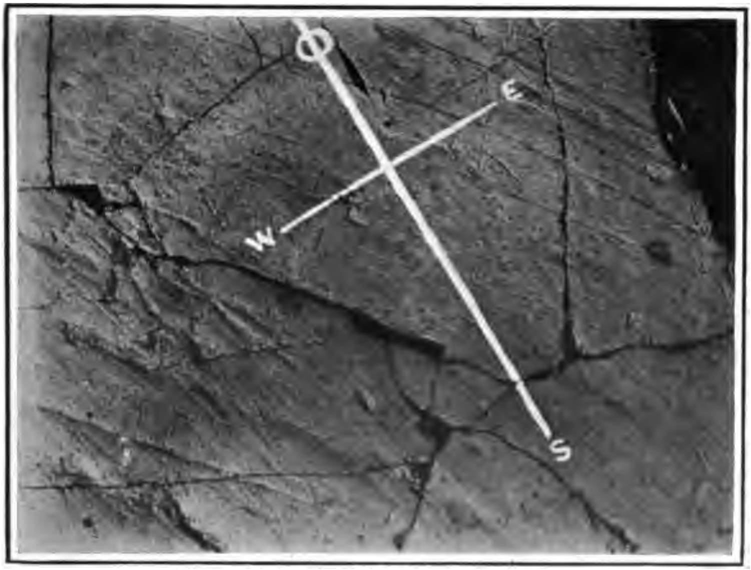

FIG. 55.—Glaciated Rock Surface, Corsiehill, Perth, showing direction of Striæ.

Photo. by ALEX. M. RODGER.

One or two of the more remarkable examples of these transported boulders, of which illustrations are given, may now be specially mentioned. On Fig. 57 is shown the rocking-stone which occurs on the summit of Craigiebarns Hill, to the north-east of Dunkeld. Beneath the large boulder are three smaller boulders, upon which the large one is seen to rest; the smaller boulders probably represent the contents of the lower portion of the clay underneath that which contained the large boulder. One of the largest boulders that we have seen is that known as the "Kirk o' the Grove." It is situated in Wester Glenalmond, and measures about sixty feet in length; it is shown in Fig. 59. Another remarkable boulder which forms a conspicuous feature in the landscape is that called "Samson's putting stone." It is perched on the edge of a glaciated hill of conglomerate near Callander; the boulder itself consists of Ben Ledi grit. The longer axis of the stone lies in a north-east direction, and it stands in a very unstable position close to the edge of a declivity. This boulder is shown in Fig. 60.

In the smooth and rounded surfaces of the *roches moutonées* we have another unmistakable evidence of this great period of glaciation. Numerous examples of these are to be met with in the Highland valleys; they appear to have been caused by the ice-sheet when it encountered an exceptionally hard boss of rock, which it could not altogether plane down, but could only round off, polish, and groove. In Figs. 53 and 54 are shown examples of such polished rock surfaces, the one at Aberfoyle and the other in Glen Turret.

The boulder-clay, or ground-moraine, which was laid down during this period of intense glaciation consists of a tough, tenacious clay, usually devoid of stratification, and full of angular and subangular boulders, many of which are smoothed and scratched. The exact conditions under which the boulder-clay, or till, has been accumulated is still a matter of much dispute amongst geologists: but the majority of writers at the present day consider it to be a true land deposit which has been formed as the bottom-moraine of an old glacier mass; the direction in which the ice flowed being indicated by the character of the boulders found within the till, these stones having been carried forwards beneath the ice. Originally the boulder-clay must have been much more extensive than it is at present; for it often attains a great thickness, and is found at very high altitudes. Towards the close of the Ice Age it must have mantled the whole of the lower ground to a depth of over a hundred feet, as well as filled up the Highland valleys; but a large part of this deposit has been removed by the local glaciers of the later glaciation, and by subsequent denudation. In Strathmore the boulder-clay is usually of a reddish colour, while in the Highland valleys the prevailing colour is pale greyish brown. Within the Highland area the boulder-clay is best seen in some of the lateral valleys, where the meagre mountain stream has not been able to do more than cut a narrow channel into it. Drs. Peach and Horne cite a striking example on the lee ridge of Ben Vane, to the west of Loch Lubnaig, where it reaches a height of 2290 feet, and is over 100 feet in thickness. Another fine section is that seen in the little glen of Balnaguard, which forms an arm of Strath Tay above Logierait, on the south side of the valley. In this particular section the clay must have a thickness

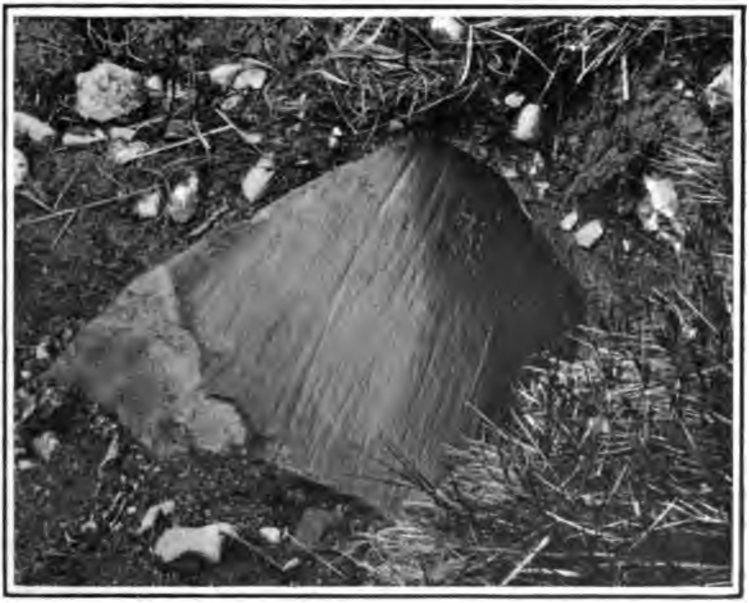

FIG. 56.—Glaciated Rock Surface, near Birnam.

Photo. by H. COATES.

of over 200 feet. Fig. 63 shows a photograph of this fine section. Further to the west, and on the opposite side of the Tay Valley, a similar section is exposed in the Derculich Burn.

In the Valley of Strathmore the boulder-clay often attains a considerable thickness. Fine sections of it are exposed in the Craigs of Maws, near Blairgowrie, and at Stormontfield, on the Tay above Perth, where it rises in mural precipices over 70 feet in height. When the railway between Crieff and Comrie was being made, a number of sections were exposed in the cuttings; the boulders in the clay exhibited a great variety both in the size and nature of the rocks of which they were composed. Many of them had been derived from the schistose rocks of the Highlands, and consisted of schistose grits, mica-schists, and epidiorites. Granites and diorites from the plutonic complex of Glen Lednock were also represented, while boulders of Old Red Sandstone conglomerate, derived from the more immediate neighbourhood were also exceedingly plentiful. As has already been pointed out, similar phenomena can be seen high up the sides of the Sidlaw and Ochil Hills, and all the evidence goes to show that the *moraine profonde* must have been transported across the Sidlaws and the Ochils, and been deposited in the lee of the hills. Professor J. Geikie says the evidence afforded by the till that crosses the southern slopes of the Ochils points precisely to the same conclusion, for that deposit is abundantly charged with fragments of gneiss, granite, and other rocks, that could only have come from the Highlands. Mr. B. N. Peach found a considerable area of till at a height of 2200 feet on the shoulder of Ben Cleuch, and numerous scattered stones occurred on the very top of the hill, 2300 feet[1] (see Figs. 61 and 62).

It is in the Arctic regions that we have the nearest approach to the conditions under which the Scottish boulder-clay was accumulated. In these northern climates snow falls on the hills indefinitely; it melts, but it does not melt so fast as it falls, and so it goes on accumulating. The melted snow finds its way into every possible crevice; it becomes ice, and in this state is a most potent factor in the disintegration of the rocks: but the accumulation goes on, and, ultimately, its weight causes the mass to slide down the hillsides, carrying the fragments of rock with it. These fragments are ground into sand or clay, according to the nature of the rock. That part of the accumulation of ice and snow which comes into immediate contact with the rock is ice, but it passes gradually upwards into soft snow, which being constantly supplied in excess of what is removed, causes a constant motion in the whole mass, both of ice and rock fragments. When the impelling force ceases by the snow becoming less, owing to the climate becoming mild, the motion is arrested, and the débris, which is the result of the freezing and the motion, gets the name of boulder-clay. As descriptive of the mode of its formation, it has been termed bottom moraine, or, as an equivalent, ground moraine, and sometimes we adopt for it the French term, *moraine profonde*. These terms have all the same meaning: they are indications of the method of formation, and distinguish the material from moraines which have been otherwise formed.

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[1] *The Great Ice Age*, by James Geikie, page 74, second edition, 1877.

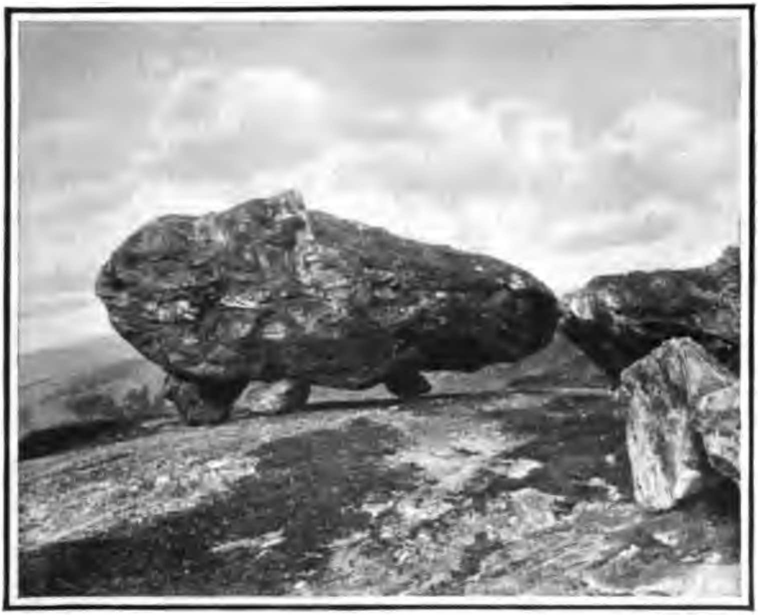

FIG. 57.—Perched Boulder on Craigie Barns, Dunkeld.
(Length 13 ft., Breadth 7 ft., Height 5 ft.)

Photo. by WM. ELLISON.

Boulder-clay is certainly morainic matter, the produce of the action of solid ice on solid land rocks, split up by that agent, assorted by that agent in its own particular way, and driven along by that agent with great force and a differential motion ; every stone that is in it, every bit of clay, every inch of the floor on which it rests, bears testimony to the fact that it has been pushed along under its own great weight, and under a greater and more active weight of ice beyond that. This appears to be the only known process of nature by which such a formation could be effected—a heavy mass of ice continually replenished by frozen snow, and owing to such accumulations continually falling to lower and lower levels. It is quite a unique deposit, and has a history of its own which is not paralleled by anything else in nature. Its history ceases when it is brought to rest, and that may be anywhere, either in the sea or out of it. Any changes which may have taken place upon it after it has come to rest are of the nature of destruction and dissolution, not of formation. Icebergs cannot make boulder-clay—it is physically impossible. They may carry it when it adheres to them, or they may assist in breaking it up and re-arranging it ; but these changes are of the nature of destruction, not of formation.

The till or boulder-clay is not one continuous deposit from top to bottom, but is often found to contain beds of sand, gravel, fine clay, and layers of peat. A moment's reflection upon the nature of these deposits is sufficient to carry the conviction of a very great change of climate. In the one case we have a state of matters where no life is possible, away down in the depths of the ice, where there is no sound but the sound of the river of ice and rock, an incessant hollow, monotonous grind; in the other we have light and heat, the brightness of sunshine with all the cheerfulness and beauty which it brings, the flutter of forest leaves, the song of birds, the hum of the busy insect's wing, and even, perchance, in the later of these periods, suggestions of the presence of man.

Overlying the boulder-clay, there occurs in certain localities a great series of sands and gravels, which are known as Kames. These deposits appear to have been laid down during the melting of the great ice-sheet, and have their counterparts in the gravelly moraines and torrential deposits of the present-day glaciers of Switzerland. Usually they consist of coarse sand and gravel, showing a more or less rude stratification, and the boulders which they contain exhibit evidence of having been water-worn. It seems highly probable that they have been formed by the rivers which flowed from the melting glaciers which still occupied the Highland glens, and which, during the summer time, deluged the lower grounds with floods of water.

Typical examples of these can be seen at Ochtertyre, near Crieff. They are well shown between the Turret Burn and the broad Carse that stretches westward in the direction of Comrie, where they consist of immense accumulations of sand, gravel, and shingle, rising into rounded knolls, hillocks, and banks. Numerous erratics are to be found, either in the deposits themselves, or distributed over their surface. These deposits are clearly of morainic, or fluvio-glacial origin, and they appear to have been formed by two glaciers; one of which was formed by the union of the glaciers that descended the valleys of the Shaggie, Kelty, Barvick

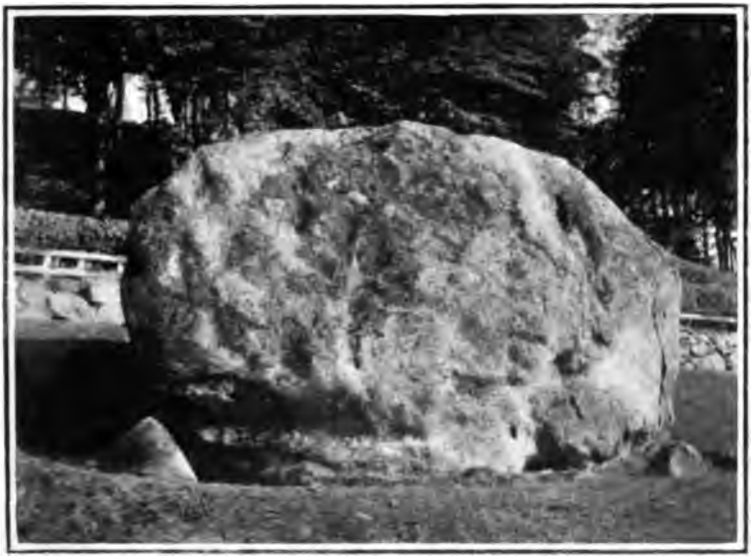

FIG. 58.—Erratic Boulder of Greywacke, near Baird's Monument, Strowan.

Photo. by D. M. GALL, B.Sc.

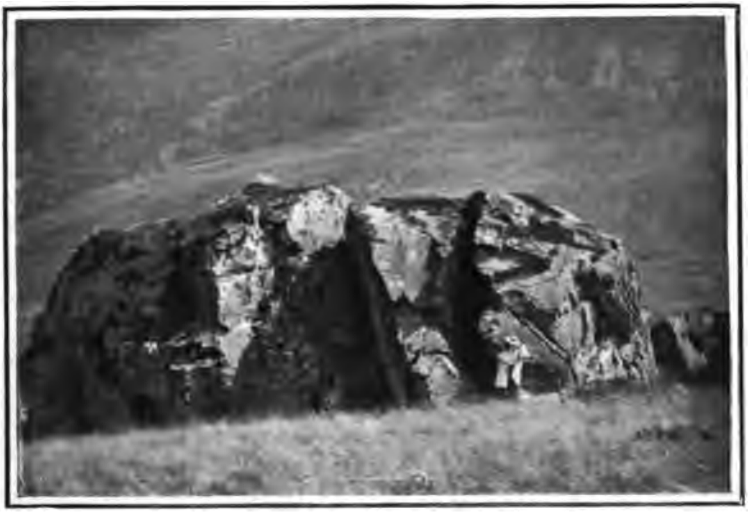

Fig. 59.—"The Kirk o' the Grove"; Boulder in Allt Caire Cultrain, Wester Glenalmond. (About 90 feet in circumference, and 20 feet in height.)

Photo. by A. S. Reid, M.A., F.G.S.

and Glen Turret; while the other came down the valley of the Earn from the Lochearnhead direction, filling Loch Earn, and extending as far east as Ochtertyre. The great masses of sand and gravel referred to consist of the moraines of these glaciers and of the material which was distributed by the streams which escaped from the melting ice (see Fig. 66).

It was partly during this vast extension of the ice-sheet, and partly during the later valley glaciation, that the rock-basins which enclose our Highland lochs were excavated. Much discussion has taken place regarding the manner in which these rock-basins have been formed, and the part which thick masses of ice have played in their production has been a vexed question. But no theory which has yet been put forward accounts so well for all the phenomena which they exhibit as that first advanced by Sir A. C. Ramsay. According to Ramsay, the greatest amount of erosion would take place at the point where the ice reached its greatest thickness, and that would be somewhere in the lower reaches of the valley. In the higher parts of the valley, where the descent is steep, the ice would be thin, but towards the bottom of this descent there would be a tendency for the ice to heap itself up, and it is at this point that the maximum amount of erosion would take place. Still further down, where the valley widened out, the ice would become thinner, and its erosive power less potent. The effect of such conditions, extended over a long period of time, would be the production of an elongated rock-basin, which would slope gently from either end, and reach its maximum depth at a point which would lie somewhere above a line drawn across the valley midway between the lower and upper ends of the rock-basin. The general trend and form of such rock-basins seem to be best explained by Ramsay's theory, and no other hypothesis which has as yet been advanced accounts so satisfactorily for all the phenomena connected with such rock-hollows. He also pointed out that rock-basins are numerous in northern and Alpine countries, while they are comparatively rare in more southern regions, or in districts far removed from mountainous areas.

Within the catchment area of the Tay there is quite a variety of types of rock-basins. Perhaps the simplest of these is Loch Earn. This loch is over six miles long, and has an average width of about three-quarters of a mile. About half-way down, the loch reaches its maximum depth of 287 feet. The great lateral fault, known as the Loch Tay fault, enters the loch on its southern side at Edinample, and crosses to Dalveich. This line of fault coincides with a small basin having a depth of 240 feet. Mr. J. S. Grant Wilson has pointed out that the *mer de glace*, crossing this part of the country in an E.S.E. direction, must have exercised its greatest pressure along the south side of the valley. This appears to be confirmed by the shape of the rock-basin, as the slope of its southern side is twice as steep as its northern.

In the rock-basin of Loch Tay, which is 14½ miles in length, with an average breadth of about three-quarters of a mile, and a depth of 510 feet, just below Skiag, we have a good example of a deflection basin. The great lateral fault, or wrench, which passes through Loch Earn, enters Loch Tay at Ardeonaig, and crosses to Fernan. This fault has a downthrow to the west, and brings the Loch Tay Limestone and associated

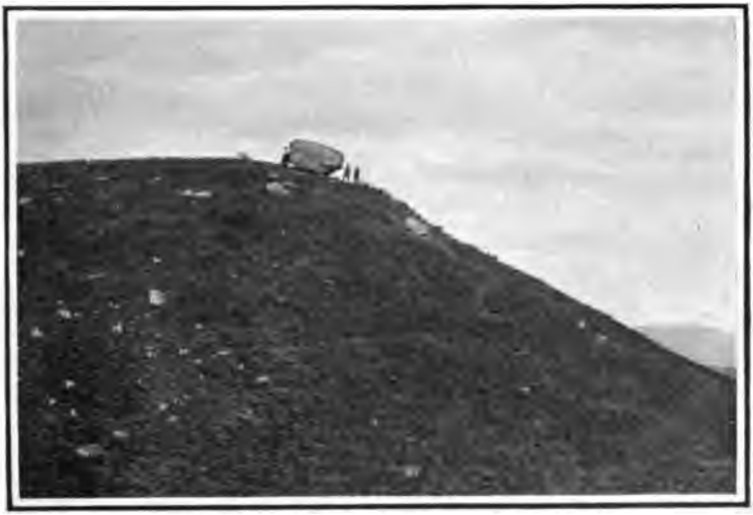

FIG. 60.—"The Deil's Puttin' Stane"; Perched Boulder on Roche Moutonnée Surface, near Callander. (10 feet long by 7 feet high.)

Photo. by A. S. REID, M.A. F.G.S.

schists against the granitic intrusions of Beinn Bhreac and Tomnadashan (see coloured sketch map of Loch Tay district). The deepest part of the loch lies along the line of this fault, and it seems more than likely that the harder igneous bosses upon the east side of the fault have offered a greater resistance to the erosive power of the ice than the softer schists on the west side, with the result that the slopes on the south side of the loch at this point would be much steeper than on the north, which would tend to cause an under-current or deflection of the ice towards the north-east. The direction of the striae seen upon the quartz-porphyry of Ardtalanaig seems to confirm this view regarding the origin of the deepest part of Loch Tay.

Loch Tummel and Loch Rannoch are both typical rock-basins. The former has been excavated out of the central Highland quartzite, which, with its associated bands of black-schist, appears to form the whole of the floor of the loch. Loch Tummel consists of three comparatively shallow basins; the deepest basin is the western one, which reaches 128 feet. A longitudinal section of Loch Rannoch shows that it gradually deepens from the western end towards the centre and eastern end. The rock-basin has been entirely excavated out of the Moine schists. Mr. J. S. Grant Wilson considers that as the ice passed along the Strath of Rannoch from east to west, the greatest erosive power of the ice would be at the eastern end, just where the glacier began to move outwards from the centre of dispersion, and that this accounts for the deepest part of the loch occurring at its eastern extremity (see Fig. 84).

Loch Ericht and Loch Laidon coincide with one of the great lateral wrenches, or faults, which have been described in the chapter dealing with the structure of the Grampians. Loch Garry and Loch Lyon also lie in the trend of similar faults. In all these lochs the longer axes coincide with the lines of dislocation.

In the catchment-basin of the River Teith there occur the following important rock-basins: Loch Katrine, Loch Achray, Loch Doine, Loch Voil, and Loch Lubnaig (see Fig. 95). We cannot, however, enter into a detailed account of their structure, but must refer the reader, who may wish further information upon that point, to the important papers, published in the *Scottish Geographical Magazine*, by Sir John Murray and Mr. Fred. P. Pullar. Loch Lomond, which lies in a deep transverse valley, exhibits all the characteristics of a true rock-basin. A map and sections of this loch are given in Professor James Geikie's *Great Ice Age*.

The fiords, occupied by arms of the sea, which trench the Grampians of Argyllshire, such as Loch Fyne, Loch Riddon, the Kyles of Bute, Loch Long, and Loch Goil, are merely submerged valleys; and many of them have been demonstrated by the Admiralty soundings to be true rock-basins, which have been excavated by glacier ice.

Throughout the Grampians there occur, often at high altitudes, small lakes or rock-basins which are quite independent of any valley system. Their sides are usually intensely glaciated, and there can scarcely be a doubt that they owe their origin to erosion by glacier ice.

Moraine-tarns have been formed by the ponding

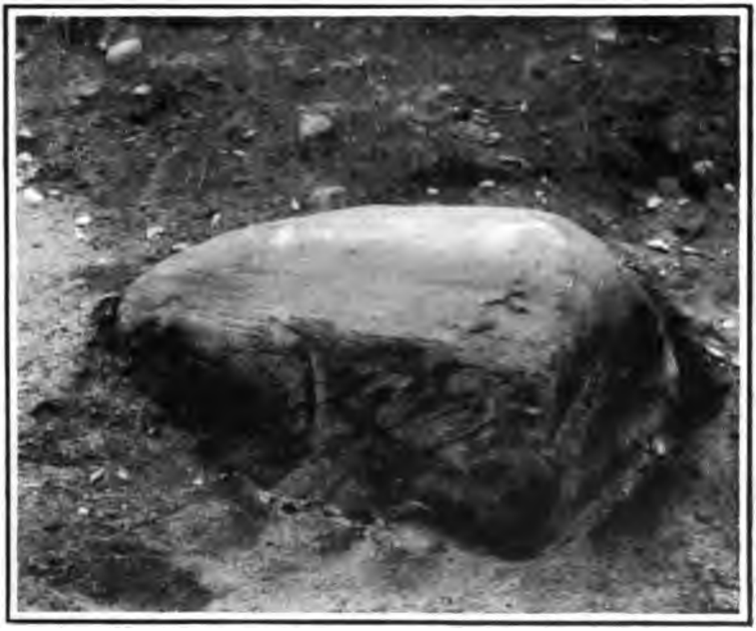

FIG. 61.—Glaciated Boulder in Railway Cutting, near Crieff.

Photo. by H. COATES.

back of a stream by moraine material, which has been thrown across the valley during the retreat of a glacier. Where the water flows from the lake, the barrier of moraine material has been cut into by the escaping stream, and in many cases this has proceeded to such an extent that eventually the lake has been entirely drained away. Numerous examples of these moraine-ponded lakes are to be met with in the valleys of the Grampians.

Still another type of lake is to be found in those which lie in cup-like hollows either in the old glacier moraines or in the boulder-clay. Fine examples of this type occur in the area which lies between Dunkeld and Blairgowrie, where there is quite a chain of lochs of this character. They include the Loch of Lows, Butterston Loch, Clunie Loch, Marlee Loch, and Rae Loch.

Everywhere throughout the Highlands there is abundant evidence of the valley glaciation that succeeded the more intense glacial conditions which have just been described. After the great ice-sheet passed away, local glaciers still continued to occupy the valleys, and they have left behind them evidence of their former existence in the striae, which coincide with the trend of the existing valleys, and also in the moraines, which are more or less extensively developed in most of the valleys. These moraines consist to a large extent of ridges or hillocks of coarse shingle, sand, and gravel, with which erratic blocks of various sizes are often associated. Both terminal and lateral moraines occur in the Highland valleys. In many instances these local glaciers appear to have been sufficiently thick to over-ride the minor watersheds. A number of examples of such have been given by Dr. Peach and Dr. Horne.[1] Thus the glacier which descended Loch Katrine passed over the low col that separates that loch from Loch Chon, while the glacier that descended Loch Voil overflowed the col between Strathyre and Loch Earn. In a similar manner the ice appears to have been thick enough to have streamed over the cols that connect such adjoining valleys as Glen Lyon and Glen Lochay.

In the valleys of Loch Eck, Loch Goil, Loch Long, Glen Fruin, and Loch Lomond numerous examples of morainic mounds are to be met with. The Glen Fruin moraine is well developed on the slopes of Shantron Hill, from which it stretches to the main Glenfruin road, past Inverlaurin, across the Fruin Water, and high up the south side of the Fruin Valley. The late Mr. Dugald Bell considered this to be the terminal moraine of a glacier which descended Glen Fruin, but Professor Gregory and Mr. J. Renwick have shown that it is much more likely to be a lateral moraine of the Loch Lomond glacier. In some of the glens, such as Glen Massan, at the head of the Holy Loch, moraines descend to within a short distance of the level of the sea.

In Highland Perthshire the moraines of the later glaciers are splendidly developed along the shores of Loch Katrine, between Stronachlachar and Loch Lomond. They are also well seen along the railway between Callander and the head of Glen Dochart. From the head of Glen Ogle, onwards to Crianlarich, the ridges and hillocks of morainic material are excep-

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[1] "Notes on the Geology of the Loch Katrine District," *The Scottish Geographical Magazine*, April, 1900, page 230.

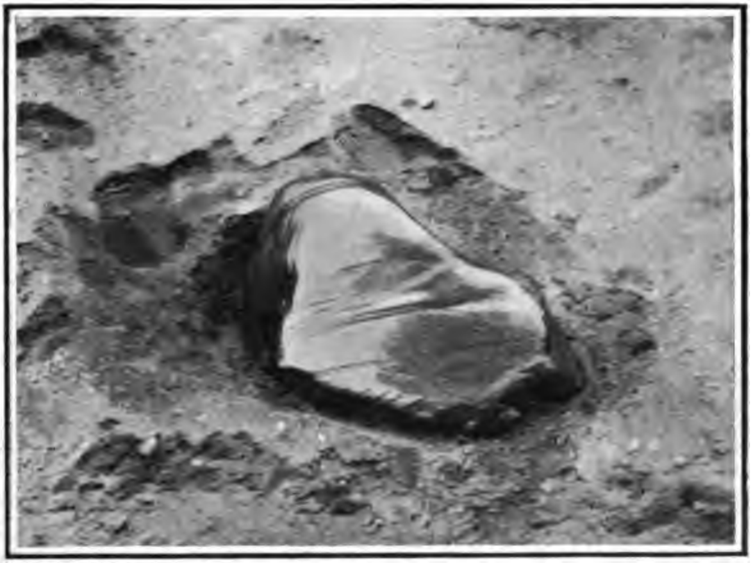


FIG. 62.—Glaciated Boulder in Boulder Clay, Railway Cutting, near Crieff.

Photo. by H. COATES.

tionally conspicuous, and this great development has no doubt been due to the highly mountainous character of the ground that surrounds the Dochart Valley, which would form an excellent gathering ground for the local glaciers. Another exceedingly fine group of moraines occurs near the head of Glen Garry, in the col between the Garry and Glen Truim.

Similar phenomena can be observed in the Grampians of Forfarshire, one of the most interesting moraines in this district being that described by Sir Charles Lyell. This moraine forms a great transverse barrier at Glenairn, in the valley of South Esk. When looked at from the south it has the appearance of an immense rampart, 200 feet high, stretching across the valley. Measured from north to south it has a breadth of about half a mile. For a space of three hundred yards the River Esk has cut into this barrier of morainic material. The deposits which form the lower portion of the rampart consist of unstratified mud charged with boulders, and having a thickness which varies from 50 to 80 feet. Above this there is a series of finely stratified materials, which in some instances reaches a thickness of over a hundred feet. Above this barrier there is an alluvial flat, which represents the site of an ancient glacial loch, the loch having been drained by the water cutting a channel through the morainic deposits. Fig. 64 shows a group of moraines in Glen Turret, Perthshire; they have been formed by the glacier descending from Ben Chonzie. Similar groups of moraines are shown in Fig. 65, near Auchnafree, Glenalmond; while Fig. 66 shows mounds of fluvio-glacial deposits at the mouth of the Sma' Glen in Perthshire.

The gradual disappearance of the glacial conditions seems to have been followed by a certain amount of submergence of the area under notice, and it was during this period that the 100-feet terrace of our great firths was formed. This ancient beach forms the upper terrace at Bridge of Allan, and skirts the Carse of Stirling, reaching as far inland as Dollar. It is farther seen forming outlying patches in Clackmannanshire. The same terrace has also been traced in the valleys of the Tay and Earn.

When these terraces are traced inland, they are seen to pass into tumultuous deposits of gravel and sand, with sheets of loam and clay; and in Strathmore they are associated with hillocks and ridges of morainic material. In the valleys of the Tay, Earn, and Forth, series of aqueous deposits are seen to rest upon the denuded surface of the boulder-clay. They have been traced to an altitude of 100 feet above sea-level, and there can scarcely be any doubt that at one time they must have filled up the whole of the valleys to that level.

In some places these deposits consist of layers of sand and gravel, while in others they appear to pass into fine brick clays. They are often seen to emerge from beneath the overlying and younger alluvial deposits, and fringe most of the so-called Inches of the Carse of Gowrie, and the valleys of the Tay and Earn, where they may be seen at Forgandenny and at Old Scone, near Perth. Near Errol, on the shores of the Firth of Tay, a brick clay which belongs to this group of deposits has yielded a considerable number of marine shells, which belong to species now only to be found living in high northern latitudes. These include

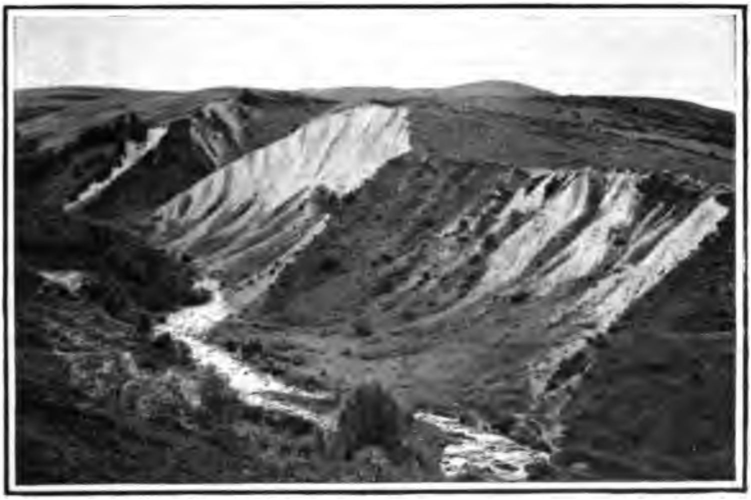


FIG. 63.—Boulder Clay at Balnaguard, near Logierait.

Photo. by H. COATES.

such forms as *Pecten islandicus*, *Tellina lata*, *Saxicava rugosa*, and others. It has long been known that post-glacial deposits of a similar character rest upon the boulder-clay which floors the whole of the Firth of Clyde. Sometimes they are seen to rest directly upon the boulder-clay, but they are also often seen to pass down into a fine-grained laminated clay, which is devoid of organic remains, with the exception of a few foraminifera. In the Clyde valley the fossiliferous clays have been found at Jordanhill, Paisley, Dalmuir, Greenock, Helensburgh, and along the Kyles of Bute. The clays are generally found to be cut away between low tide and high water mark, where the abrading power of the water is greatest. Occasionally the sands, gravels, and clays of these deposits show evidence of crumpling, and it has been inferred from this, as well as from the existence of boulders in the brick clays, that floating ice must have existed in the sea during the period of their deposition.

The still more recent post-glacial deposits consist of raised beaches and clay flats, which occur between sea-level and the 50-feet contour line above mean sea-level. The most widely distributed, and perhaps the most important, of these deposits is that known as the estuarine or carse-clay, which forms the elevated alluvial levels known as carse lands. Near the sea-board the surface of these levels is from 25 to 30 feet above the surface of the sea, and their borders coincide with a line of raised beach at the same level. When traced inland their surfaces are seen to rise gradually to a level of about 40 or 50 feet, and when they reach this altitude they pass into fresh-water alluvium, while their lateral portions thin off against the raised beach which marks the 50-feet contour line. Good examples of these are seen in the Carse of Gowrie and in the Carse of Stirling. The clays and silts of this terrace contain marine shells, of which *Scrobicularia piperata* and the oyster are the commonest. Near the base of these deposits there frequently occurs a bed of peat, in which trunks and rooted stools of trees occur. In certain localities in the valleys of the Tay and Earn this peat-bed is seen to pass below the mean level of the sea, when it has been called a submarine forest-bed.

From a consideration of all the evidence, it seems highly probable that the buried trees of the Tay, Earn, and Forth valleys grew at a period when the whole of North-Western Europe was covered with a dense growth of forest trees, great parts of which along the sea margin have now been submerged. The evidence of the former existence of this forest area is not, however, confined to the maritime districts alone, but has been traced far inland below the more recent peat-bogs. Along the Firth of Tay it has been observed at Newburgh, Flisk, Errol, and Pitfour, and it has also been traced westwards over a large portion of Strathearn as far as Aberdalgie. Near the junction of the Earn and the Tay the peat-bed fills up a large portion of the channel of the stream, where it has been a source of great annoyance to salmon fishers, whose nets become entangled in it, and by whom it is often dragged to the shore in large masses.

In the valleys of the Tay and Earn the carse-clay and peat are seen to be underlain in certain places by river gravels, which along with the submarine extension of the peat serve to show that when they were formed the land must have stood at a much higher level than

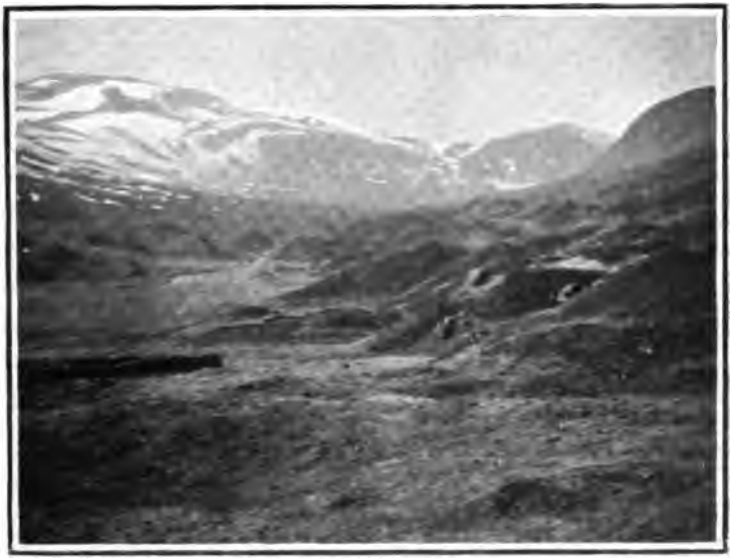


FIG. 64.—Moraines at Head of Glen Turret.

Photo. by S. T. ELLISON.

it does at present. The forest-bed and peat indicate that after the passing away of the glacial conditions there was a general increase of the land, and it seems probable that at this period our islands were united among themselves, and also to the mainland. Across this land connection migrated in succession the arctic-alpine and temperate faunas and floras. Eventually the climate became much more genial, and great forests covered the whole of the land, spreading northwards into latitudes now far beyond the limits of the same species of trees.

As the sea gradually encroached upon this old forest land, vast quantities of sand, silt, and clay were brought down and deposited around and over the trees. We may easily picture to ourselves many giants of this primeval forest rearing their blackened trunks for long ages amid the desolation of great mud-flats, until they were overborne by the tempests that swept in fury up the estuary, or became clasped in the death-grip of the ever-steadily accumulating sediment.

It was during the period represented by the carse-clays which overlie the forest-bed that Neolithic man first invaded Scotland. As we have shown, these deposits indicate that the forest period was succeeded by a submergence of the land, during which time the estuaries of the Tay and Forth reached much further inland than they do at present. For a long time, then, those parts of the Tay, Forth, and Clyde valleys, which are now covered with the carse-clays, must have formed wide shallow estuaries, into which, year after year, and century after century, the rivers poured vast quantities of gravel and silt, mixed with vegetable débris. It is in this old river drift, which succeeds the laminated clays, and which is only covered by the surface soil, that we find the first traces of the early inhabitants of our country; his former presence being indicated by the large number of rude canoes and stone implements which have been found in these deposits.

We can easily conjure up in imagination that long bygone time when the land stood at a lower level, and what are now the sites of such populous towns as Glasgow, Stirling, and Perth were covered by broad sheets of water. Along the shores of these ancient estuaries there wandered tribes of Neolithic men, the first boat-builders of the Clyde. The great number of rude canoes which have been disinterred from the alluvial deposits that underlie the streets of Glasgow show that from time immemorial the Clyde has been a favourite locality for the construction of vessels. But what a wonderful change has taken place since primitive man first built his huts upon the banks of that river and made his first rude efforts to adventure upon the face of the deep.

To-day the banks of the Clyde are lined with miles upon miles of streets and squares. The air is filled with the noise of a thousand anvils, upon which the skilled artisan is busy at work fabricating the great ocean liners, "the shuttle of our Empire's loom." Huge vessels are continually passing up and down the river, carrying bales of merchandise to or from the uttermost ends of the earth. Day after day the streets are filled with the din and noise of ceaseless traffic, which grows greater and still greater as the years roll on, while a million human beings jostle each other, each with eager face, bent upon the pursuit of his own particular avocation.

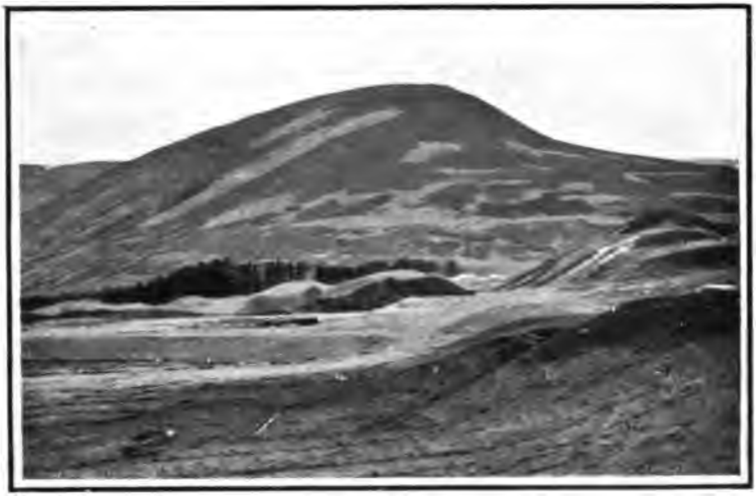


FIG. 65.—River Terraces and Moraine Mounds, near Auchnafree, Glenalmond.

Photo. by A. S. REID, M.A., F.G.S.

Yet, within—geologically speaking—comparatively recent times, our rude forefathers hunted the denizens of the deep over what is now the site of the great city, or chased the red-deer in the dark forests that swept on to the distant horizon. In imagination you can hear that old forest resound with the shouts of the huntsman; you can see him push his canoe from the shore in pursuit of the quarry which is escaping across the estuary, and then you can see him deal the death-blow and drag it triumphantly to the shore. And yet the period of time that separates the dug-out from the great ocean liners is but an episode in the vast cycles of geological time. For countless ages Nature was at work, planting the coal and sculpturing out our noble Firth, preparing the Clyde valley for the future abode of man. During these long ages there was no intelligent eye to behold the mighty revolutions that were taking place. But, as we have seen, Nature began to weary of this eternal donning and doffing with no eye to behold its glory, and so she called into existence the man-child, who was destined to penetrate even to her innermost secrets. These long ages of striving and waiting have been finely expressed by Emerson in the following lines:

My boreal lights leap upward,
Forthright my planets roll,
And still the man-child is not born,
The summit of the whole.

Must time and tide forever run?
Will never my winds go sleep in the west?
Will never my wheels which whirl the sun
And satellites have rest?

In the Alpine flora of the Scottish Highlands we have the still living representatives of the plants that first invaded our country after the close of the intense glacial conditions which prevailed during the Great Ice Age. It is a remarkable fact, which has long been known, that there are certain areas in the Highlands very much richer in Alpine plants than others; thus, on a series of mountains stretching from Ben Lui, on the confines of Perthshire and Argyllshire, north-eastwards through Meall Ghaordie, and along the ridge bounding the north of Loch Tay, and including such high peaks as Creag na Caillich, Meall nan Tarmachan, Beinn Ghlas, and highest of all, Ben Lawers, and from Breadalbane north-eastwards into Clova, we find an exuberant development of Alpine plants. This tract may be defined as the Ben Lawers ridge. The Alpine character of the plants on this series of mountains has long been well known, and accurate records have been made of the different species which occur on it.

The second group of mountains also begins at Ben Lui, and stretches northwards by the heads of Glen Lochay and Glen Lyon, and includes the following mountains: Cam Chreag, Creag Mhor, Beinn Heasgarnich, and others. This may be defined as the Mamlorn ridge. The flora of this ridge has not been examined to the same extent as that of Ben Lawers, but what plants have been gathered tend to show that it approaches very closely to the Ben Lawers type.

We cannot here discuss the origin of the Alpine flora of the Scottish Highlands, but it may simply be pointed out that the tendency of recent investigation has been to show that it survived the period of intense cold in the British Isles. It is also generally believed that the migration of these plants could only have taken place by means of a land connection, and that

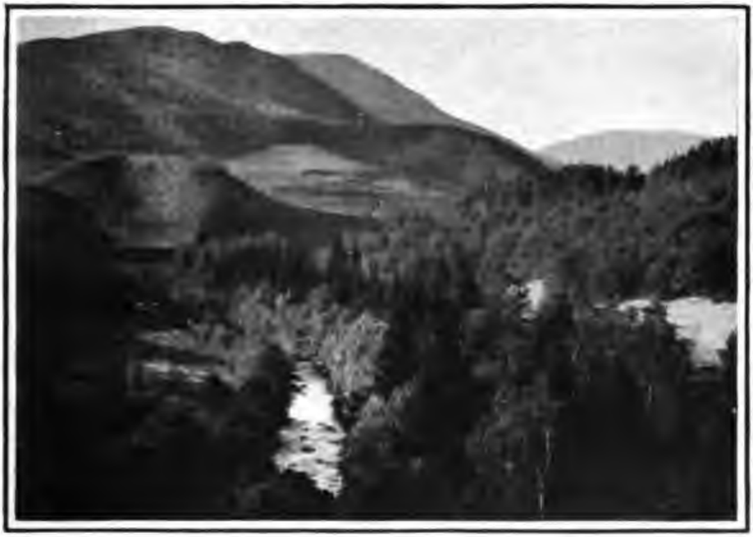


FIG. 66.—Mouth of the Sma' Glen, showing Mounds of Fluvio-Glacial Deposits.

Photo. by A. S. REID, M.A., F.G.S.

the Alpine flora was at first a lowland flora, which was drawn inch by inch and yard by yard to the hills, and eventually to the highest mountains.

In dealing with the present distribution of the Alpine flora in the Highlands, we have attempted to show that the mountains richest in such plants, namely, those forming the ridges just described, coincide with the outcrop of schists known geologically as the Ben Lawers phyllites. The minute structure and mineralogical characters of these schists have been described in an earlier part of this work. The structure known as *Ausweichung*, or strain-slip, has been a most important factor in determining the present existence of Alpine plants on these mountains.

This strain-slip structure has been produced by the intense folding which the rocks have been subjected to, and by the development of a series of minute divisional planes crossing the earlier foliation.

The effect of these minute divisional planes has been to make the schists exceedingly friable, so that they become easily disintegrated, and thus form a suitable soil for the nourishment of the Alpine flora. It may be also pointed out that the importance of the mechanical structure of the schists in the distribution of these plants is conspicuously shown in the great cliffs of phyllite covered with an exuberant Alpine vegetation, and that upon these cliffs many of the Alpine plants are anchored like limpets to a rock.

There can be no doubt that this outcrop of schists has been the most important factor in the determination of the present distribution of our Alpine flora. Other factors, however, enter in, such as altitude, meteorological and physical conditions; while the subject is further complicated when we bear in mind that the Mamlorn and Ben Lawers ridges must have acted as secondary centres of dispersal from which these plants must have been distributed in the more immediate neighbourhood of these two areas.

If we ascend to the summit of Ben Lawers we shall find that the Ben Lawers phyllites have been weathered into a series of rock-girt pits or hollows, which form the abode of *Saxifraga cernua*, its only station in Great Britain. Adopting the theory that it, with its fellows, once covered the Lowlands, its solitary position here has not been inaptly called its last citadel. Step by step the upward march of the Germanic flora has pushed it from the plains to the hills, and from the hills to the mountains; one by one the mountain citadels have fallen, the result rather of starvation within the walls than of assault from the enemies without, till here, on the summit of Ben Lawers, it takes its last stand in the final struggle (see Figs. 26, vol. i. and 93). Along this ridge of mountains many other Alpine species are to be found, as *Gentiana nivalis*, *Salix herbacea*, *Saussurea alpina*, *Erigeron alpinus*, *Dryas octopetala*, while on the Clova mountains, and on the same belt of schist, we have many of the Breadalbane plants and others which are confined to the Clova mountains alone, as *Carex alpina*, *Astragalus alpinus*, etc.

We have climbed Ben Lawers in all seasons of the year, in storm and in calm, in mist and in sunshine. We have even ascended to the summit when the upper 2000 feet was enveloped in a thick mantle of snow, and the wind came howling in long-drawn gusts from Glen Lyon below, sheeting the cairn on the summit with

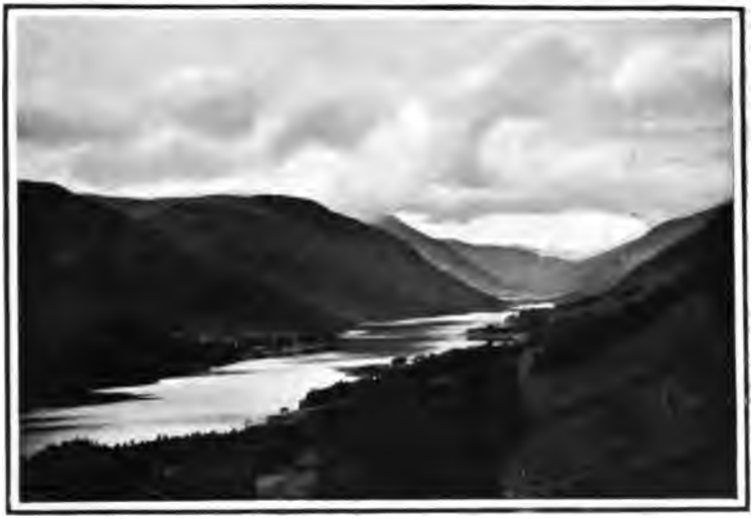


FIG. 67.—Loch Voil, from the slope of Meall ant Seallaidh, showing Glaciated Contour of Valley.

Photo. by A. S. REID, M.A., F.G.S.

snowdrift. On many occasions we have spent whole nights upon the top of the ridge that we might behold the sun rise upon a new day. During one midnight ascent the entire ridge, from end to end, was flooded in the mystic beams of a soft summer moonlight, and the weird shadows of great cliffs cast themselves in deep solemnity upon the waters of the mountain tarn lying gloomy and dark in the depths below. It was, perhaps, under this aspect that the mountain made the most profound impression upon our mind. But dearest to our memory is our first sight of the precipices that form the western side of the mountain, upon which grew the blue gentian of the snow, the mountain forget-me-not, and the white roses of the dryas. Associated with these Alpine flowers are the memories of such distinguished botanists as Lightfoot, Stuart, Don, Greville, Hooker, and others whose eyes, no doubt, sparkled with as keen a delight as ours when they beheld them for the first time.

CHAPTER XIV

ALLUVIAL AND RECENT DEPOSITS

Loud is the vale! the voice is up
With which she speaks when storms are gone,
A mighty unison of streams!
Of all her voices one!

Loud is the vale;—this inland depth
In peace is roaring like the sea;
Yon star upon the mountain-top
Is listening quietly.

WORDSWORTH.

THE alluvial deposits that have been accumulated along the courses of the rivers, and upon the floors of the lakes, present many interesting features in the area under notice. It is in the Highland part of their course, where they have a considerable fall, that the excavating work of rivers is most strongly marked. When they emerge from the Grampians on to the broad valley of Strathmore the rivers have not sufficient fall to allow of their doing any active work in the deepening of their beds, and they are then seen to flow placidly over a broad flat plain in gently winding curves. Let us glance briefly at the manner in which the river has worked in the formation of such an alluvial plain. If we stand on the inner side of one

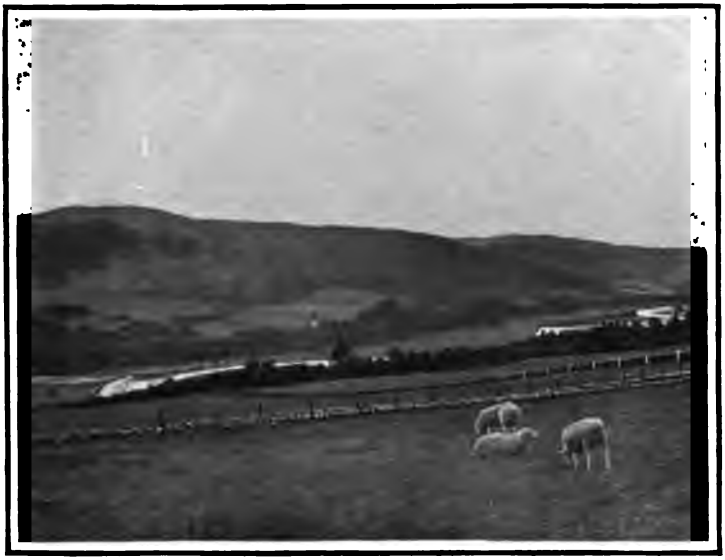


FIG. 68.—Strath Tummel, from the Braes of Tullymet.

Photo. by J. S. GRANT.

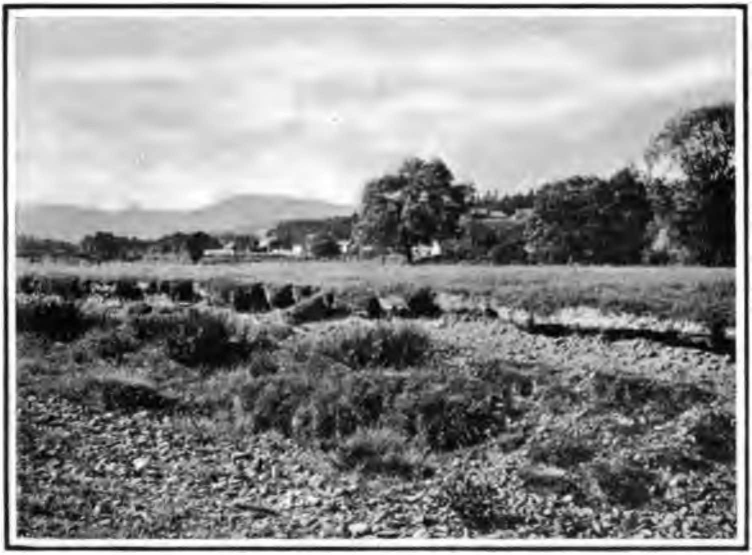


FIG. 69.—Inch Farm, Ballinluig, showing edge of Lower Haughland, with shingle bed in the foreground.

Photo. by H. COATES.

of the bends or curves which the river makes in its course across the plain, and face the river, we shall usually notice that behind there spreads a rich flat meadow-land, whilst in front the bank rises steeply into a rough scaur or newly-cut cliff. Sweeping rapidly round the convex part of the bend, the river impinges on the foot of the cliff or scaur, and is continually undermining it, so that, from time to time, great masses of rock are brought down and carried onwards by the stream. On the inner part of the curve the water is shallow, owing to the accumulation of gravel, sand, and mud, which have been dropped in this position, as the current which brought them down is here too feeble to carry them onward. The result is that the sweep of the river becomes gradually lengthened, and the outer or convex side of the bend is slowly undermined, while the inner or concave side is being slowly built up. In the accumulation of these banks of alluvium we have the first step in the production of an alluvial flat, the completion of the process taking place during the periods of flooding, when the rivers overspread the alluvial flats and fill up their inequalities by the deposition of layers of sediment upon them (see Figs. 69, 72, and 73).

The pools which have been formed at the elbows of such river curves, as has been described, have been termed deflection pools. A mobile fluid passing over a variable bed can, under the very nature of the circumstances, scarcely ever cut for itself a straight course. Inequalities, either in the rocks themselves, or in the channel, or any weaknesses in the banks, will have the effect of directing the course of the stream either to the one side or to the other. When the stream or river has been deflected in such a fashion, it begins to cut sideways, eating out such a curve as has already been described. The shape of the bottom changes, and the deepest part of the stream, which in cross-section had a V or U shape, is now forced to the one side. When the stream has rounded the curve, it shallows and passes onwards; but one curve gives rise to another, and in this way it forms a succession of curves and pools. Fine examples of such curves and deflection pools can be seen in the valley of the Earn. In the distance of about three and a half miles, between Dupplin and Bridge of Earn, the River Earn is seen to follow all the points of the compass, sweeping backwards and forwards upon itself over and over again in the most extraordinary fashion. Similar phenomena are also shown in the valleys of the Tay and Forth.

One of the results of such river action is the intermittent planing out of the strata that form the floor of the valley. This action may be compared to that of a gigantic curved knife, with its blade lying flat, which cuts into the strata forming the bottom of the valley. In this way the stream leaves not only a broad flat plain behind it, but it also forms a bank or terrace along the base of which it has passed.

In some instances the river in its windings accentuates the curves to such a degree that portions of the channel are cut off from the main stream, and form what is known as a deadwater. As a result of the long-continued action of the river eating into the outer bank, and the piling up of beds of gravel upon the

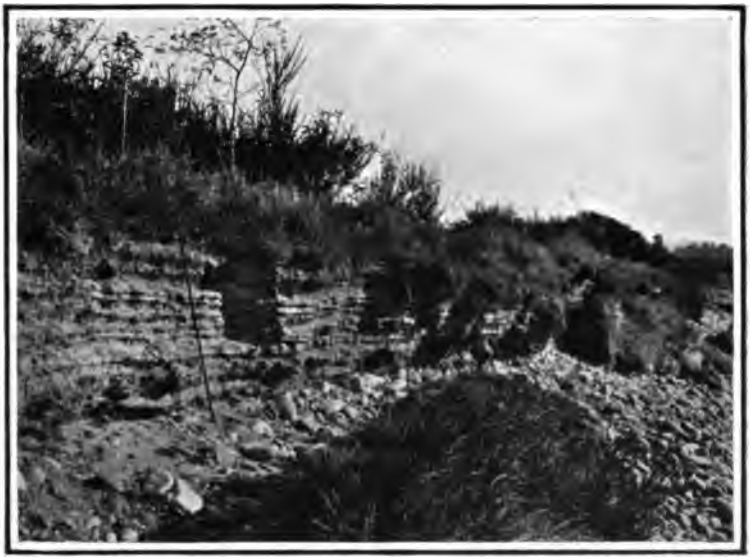


FIG. 70.—Edge of Richard's Island, near Ballinluig, showing Section of Stratified Silts.

Photo. by H. COATES.

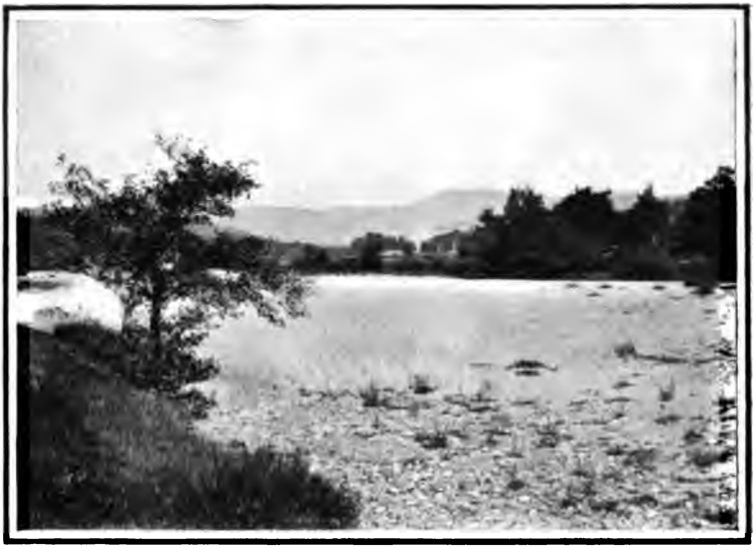


FIG. 71.—Dry Watercourse between Richard's Island and Lower Haughland, showing shingle overspread by recent deposit of sand and gravel.

Photo. by H. COATES.

inner bank, the curve becomes gradually longer and more circular in form. In the course of time the two ends of the curve will approach closer and closer to each other, till eventually they will unite, leaving the old course as a deadwater. This phenomenon occurs more frequently in those rivers which have broad valley floors than it does in those which have a more constricted area. It is also more common in a slow winding river than in a fast stream. Fine examples of such deadwaters or cut-offs can be seen in the River Earn, between Dupplin and Bridge of Earn (see Fig. 75).

Fig. 73 shows the windings of the River Tummel between Tynreich Island and Ballinluig Island. It illustrates very well the manner in which a river may deposit great beds of shingle on the inner curve, while it is continually denuding the outer one. Fig. 75 shows a deadwater opposite Big Island, above Guay on the River Tay. It has been cut off from the main stream in the manner already described. Two conspicuous terraces also appear in this photograph, on the left and right of the stream, but these will be referred to later on. In Fig. 79 a similar deadwater appears in the foreground, while in the distance is seen the junction of the Tay and Tummel, with the wooded hill of Killiehangie between. The wide valley floor is entirely composed of alluvial material which has been accumulated by river action.

It is not an uncommon thing to find old river terraces, perched at different heights, on the flanks of a valley. These generally consist of deposits of sand, gravel, and silt, similar to the alluvial deposits which have just been described, and there can be no doubt that in many cases they are simply the remnants of alluvial flats that were formed when the river flowed at higher levels than it does at present. Playfair, with his characteristic insight into geological processes, says: "When the usual form of a river is considered, the trunk divided into many branches, which rise at a great distance from one another, and these again subdivided into an infinity of smaller ramifications, it becomes strongly impressed upon the mind that all these channels have been cut out by the waters themselves, and that they have been slowly dug out by the washing and erosion of the land, and that it is by the repeated touches of the same instrument that this curious assemblage of lines has been engraved so deeply upon the surface of the globe. The changes which have taken place in the courses of rivers are to be traced, in many instances, by successive platforms of flat alluvial land, rising one above another, and marking the different levels on which the river has run at different periods of time. . . . Each change which the river makes in its bed obliterates at least a part of the movements of former changes. . . . only a part of the progression can leave any distinct memorial behind it" (see Figs. 75, 78, and 80).

Since the time of Playfair quite a variety of opinions have been held regarding the origin of these terraces. Some of these may simply be mentioned here. Robert Chambers, who was the great champion of the marine theory, believed that the sea had been the principal agent in the production of most of these terraces, and he speaks without any hesitation of the sea rolling grandly into the innermost recesses of the Highlands.

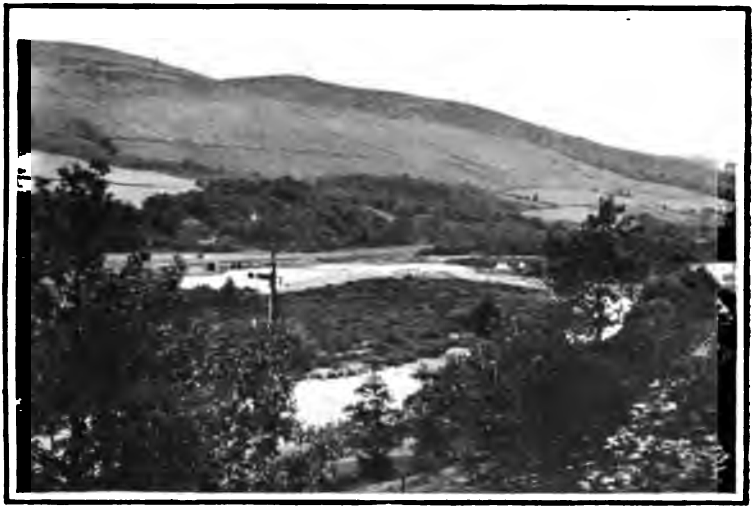


FIG. 72.—Islands above Moulinearn, recently clothed with young wooding.

Photo. by H. COATES.

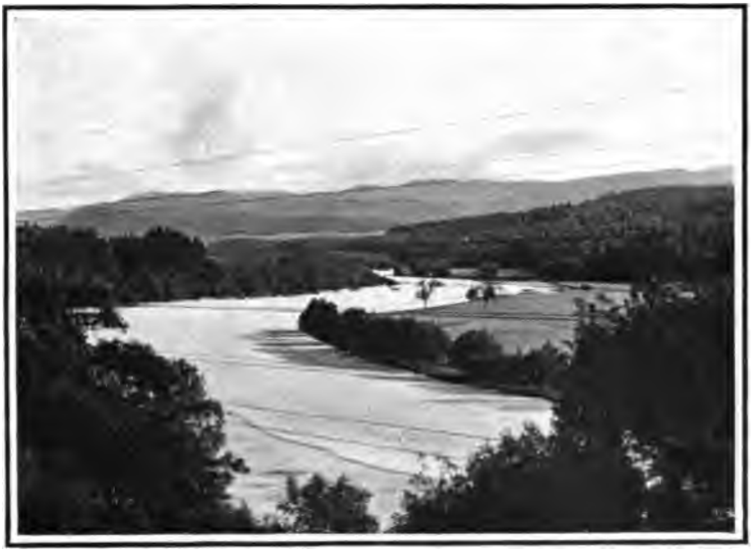


FIG. 73.—Windings of the Tummel between Tynreich Island and Ballinluig Island, with deposits of shingle on Inner Curves.

Photo. by H COATES.

He speaks confidently of "a time when the sea stood somewhat more than 280 feet above its present height, and sent an estuary up to Faskally," near the junction of the Garry and Tummel, his evidence for this being the terraces which exist in that neighbourhood. Another theory which has often been put forward to account for these terraces supposes that they are the margins of ancient lakes, which have been tapped at various stages. The well-marked terraces seen on the banks of the River Tay, which extend from the Pass of Birnam northwards to Pitlochry, have been attributed by the officers of the Geological Survey to a glacial lake formed by a barrier of morainic material. Other theorists have attributed such terraces to morainic débris, banked up against the sides of melting glaciers, or considered that they are the indented margins of great floods, which once rose high above the level of the present rivers. While some of these terraces may have been formed in such exceptional ways, it seems highly probable that the majority of them are nothing more nor less than ancient river flats, and are due to the unaided operation of rivers which have gradually worked themselves from level to level in the ordinary course of valley excavation, the erosive action of the river having been liable to impulses due to various causes.

In the catchment basin of the Tay many fine examples of river terraces are to be met with. The valley of the Tay proper presents numerous evidences of terrace phenomena. Near Kenmore, where the river emerges from Loch Tay, there is a series of remarkably fine river terraces, upon one of which Taymouth Castle is situated; they have been described by Chambers and MacLaren. The officers of the Geological Survey have pointed out that, as a river flowing out of a loch carries no sediment, the alluvial material out of which the terraces have been cut must have been derived from the moraines left during the glacial period, fragments of which are seen to emerge from beneath the alluvium.

From Aberfeldy to Grandtully the valley of the Tay becomes comparatively narrow. In this part of its course the river has cut its channel through the glacial deposits, but the alluvial terraces are not of much importance.

Between Grandtully and Inchmagranachan, near Dunkeld, there occurs a series of well-marked terraces, which have recently been attributed by the officers of the Geological Survey to a glacial lake origin. They have pointed out that near the head of the Pass of Birnam, where the valley has been much constricted, owing to the outcrop of the hard Ben Ledi grits, there occurs an extensive development of kamiform accumulations. The deposits consist for the most part of coarse gravel, with occasional large boulders, which stretch across the river, filling the whole pass and extending to the neighbourhood of Dunkeld (see Figs. 75, 78, and 80).

It is supposed that as the ice retreated up the valley these deposits constituted a barrier, above which a lake was formed, this taking place towards the close of the valley glaciation. Immediately to the north of the barrier of morainic material there is seen a terrace having an altitude of 354 feet above sea-level. It can be traced northwards to Dalguise, a distance of two miles. The deposits which form the terrace consist of soft yellow sands, and they are considered

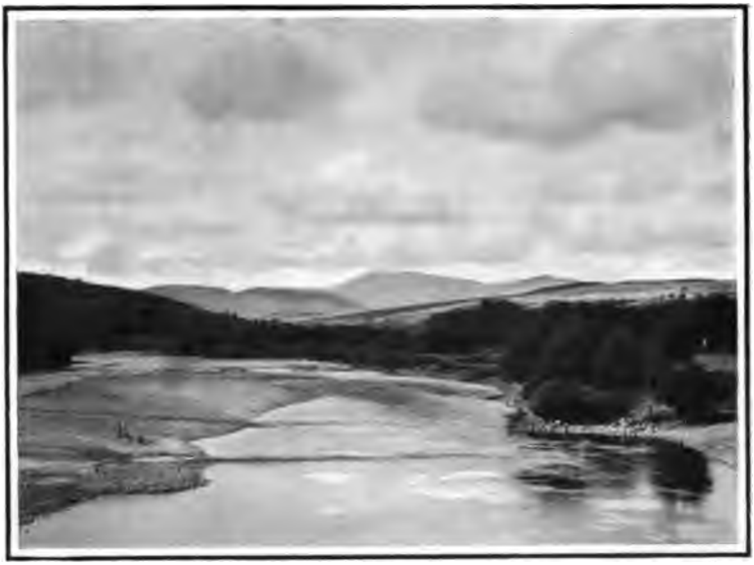


FIG. 74.--River Tummel from Ballinluig Bridge, showing recently formed "Stauners," or Islands of Shingle.

Photo. by H. COATES.

by the officers of the Survey to be of lacustrine origin. The continuity of the terraces has suffered to a considerable extent by subsequent denudation, but notwithstanding this they are clearly defined, forming conspicuous and characteristic features in the landscape. In some cases they take the form of a shelf, which can be traced for long distances along the hillside; in others they appear as spurs, projecting into the valley. In both cases, however, they are characterised by sloping sides and comparatively flat tops. Where sections of the terraces are exposed by the burns which cut through them, they are seen to consist of fine yellow silt, disposed in horizontal layers and resting upon boulder-clay.

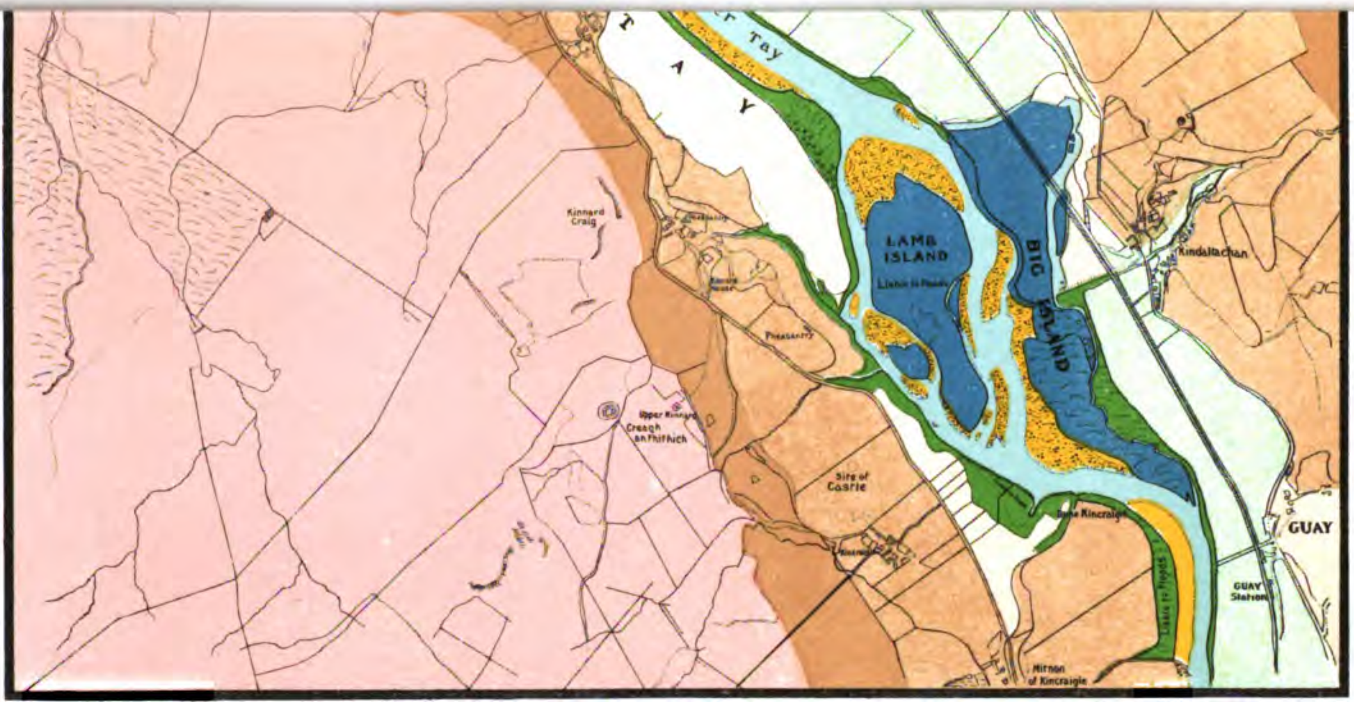
The 354 feet terrace indicates the highest level at which the ancient lake stood; during this stage it appears to have extended as far north as Guay Station. The next terrace in descending order occurs at an altitude of 318 feet above sea-level. This terrace is exceedingly well marked on both sides of the Tay and Tummel, and can be traced as far north as Pitlochry and Grandtully.

A still further fall in the level of the lake is recorded by the terrace which occurs at 269 feet above sea-level, and which shows a lowering of the lake to an extent of 49 feet. On the west side of the valley this, the lowest terrace of the three, can be traced, with only a few interruptions, from the barrier at Birnam to the junction of the Tay and Tummel. On the east side of the valley the line of terrace is not so continuous, it having suffered greatly from subsequent denudation. To the south of Dalguise station the lacustrine deposits, which are exposed in a sand-pit, have been crumpled to a considerable extent, and seem to indicate the presence of floating ice. The upper limit of the lake, in the Tummel valley, was near Logierait. Above this the lake deposits pass into terraces of fluvio-glacial origin.

Below the level of the lowest terrace the River Tay has formed two well-marked haughlands, as it winds along the bottom of the ancient glacial lake, these being bounded on either side by the more ancient terraces of the lake. The accompanying sketch map of the Middle district of Atholl shows the more recent haughlands coloured green. Above those undoubted river deposits we have the first, second, and third terraces coloured in different shades of brown. Like the other terraces of the Tay valley, this particular group has been variously referred to marine, lacustrine, and river action.

Mr. Henry Coates, who dissents from the conclusions arrived at by the members of the Geological Survey, considers that the terraces are simply the result of ordinary river action. He explains the manner of their formation by supposing that, after the close of the glacial period, the valleys were filled with a great thickness of boulder-clay and other glacial deposits, and it was out of these that the rivers carved the terraces we have described, the fine yellow sands, clays, and silts, which form the terraces, having been derived by river abrasion from the glacial deposits. He also points out that there is a very close analogy between the sections exposed in some of the undoubted river deposits and those seen in the sections of the various terraces, one particularly good example being exposed at Moulinearn. A photograph of this is shown in Fig. 11.

Mr. Coates agrees with the officers of the Survey in



[illegible] Lithographic Co., Ltd., London.

Drawn by A. Folkarde Perth

considering that the highest of the terraces may be of fluvio-glacial origin, as it seems most likely that towards the close of the Ice Age much of the work was due to the combined action of river and ice. He maintains, however, that though the lake theory appears to afford a simple and somewhat fascinating explanation of the lower terraces, yet the deposits are not such as could have been formed in a lake. He also adds: "If it is admitted that the most ancient terrace of all is of fluvio-glacial origin, why is it necessary to suppose that this action was suspended while for a period the valley was first converted into a lake, and then reconverted into a valley?"

At Luncarty, about five miles to the north of Perth, insulated platforms of sand and gravel appear at an altitude of about 85 feet above sea-level. They vary from 50 up to 100 yards in diameter, and present flat table-like tops, which have been cut out of a bed of alluvium by ordinary river action.

In the neighbourhood of Perth there occur a number of terraces at different elevations above the level of the Tay. The ground on which Perth stands, and the North and South Inches, forms the lowest of these terraces. The Inches consist of great stretches of alluvial material, their estimated level above the Tay at full tide being 10 feet. On the west and north sides the Inches are all bounded by a well-marked acclivity, and behind this is a second plain, having an altitude of 12 feet above the North Inch. The road to Dunkeld passes through it. Behind this is still a third terrace, which in some places is so sharply cut as to give one the impression that the river must have washed its base within comparatively recent times.

The alluvial deposits of the old river terraces, seen at Perth, rest upon the post-glacial deposits, which have been described in Chapter XIII. They consist for the most part of coarse gravel and shingle, with occasional large boulders, indicating the action of more or less torrential water. The succession of the glacial and post-glacial deposits, and their relationships to the more recent alluvial terraces, is very clearly shown in the Tay valley below Perth. At the base, and resting upon the solid rock, is a variable thickness of till or boulder-clay. This is succeeded in turn by the late glacial clays, the peat and forest-bed, and the carse-clay. Resting upon the carse-clay we have, in succession, three well-marked river terraces of alluvial origin.

Terraces of a similar character to those described can be seen in all the principal tributaries of the Tay. In the Pass of Killiecrankie, on the River Garry, two terraces have been observed by Chambers, one being of great historical interest, as it was upon this terrace that the Battle of Killiecrankie was fought in 1689. The officers of the Geological Survey consider that they have here evidence of another glacial lake similar to that which existed further down the valley, between Pitlochry and Dunkeld.

The lake is supposed to have extended from the head of the Pass of Killiecrankie to the Clachan of Aldclune, and its level is marked by the gravel terrace at Urrard House, which has an elevation of 497 feet above sea-level. The terrace terminates near the mouth of the Allt Girnaig in a great fan of sand and gravel, while at Aldclune it abuts against the terminal moraine of the glacier that descended Glen Garry. It has been suggested that the subsequent cutting out of the gorge

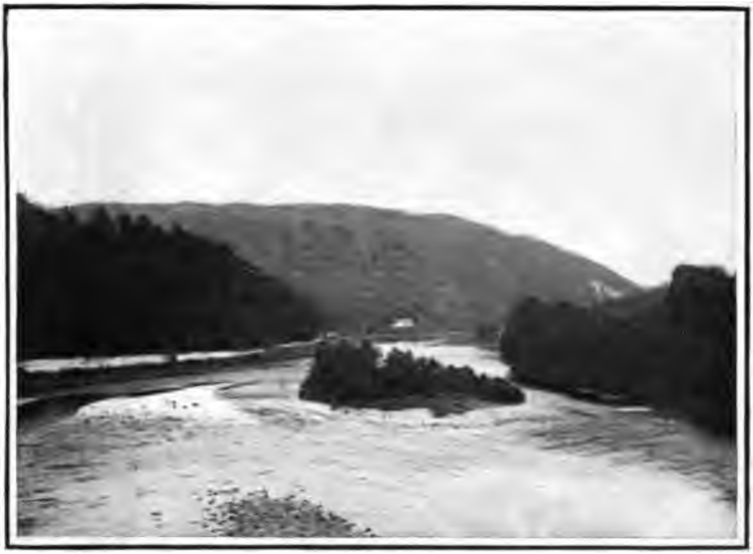


FIG. 76.—Wooded Island in Tay, below Dunkeld Bridge.

Photo. by CHAS. KIRK.

in the Pass of Killiecrankie would eventually drain the lake, "the formation of which was rendered possible by the erosion of the black schist and limestone north of the harder quartzite ridge at Killiecrankie, which arrested denudation and constricted the flow of the glacier."[1]

Two conspicuous terraces run along the sides of the River Lyon for a distance of four or five miles above Chesthill. They are quite level, and are more or less continuous. This flat of alluvium marks the former position of a lake, caused by the ponding back of the water of the Lyon. The River Lyon in pre-glacial times appears to have drained into Loch Tay somewhere in the neighbourhood of Sron Fearnan. The earlier course between Easter Achtar and the loch has been choked up with a deposit of boulder-clay.

Proceeding to the valley of the Isla, we there find terraces of a similar character to those seen in the Tay and Garry. Near the junction of the Tay and the Isla there is a terrace running along the border of the latter stream at an altitude of 146 feet above sea-level. A still higher terrace occurs at an altitude of 184 feet, and it is upon the broad tableland of this that the village of Meikleour is situated.

Throughout the valley of the Earn numerous terraces occur in association with that river. These were described in 1870 by the Rev. Thomas Brown in a paper contributed to the Royal Society of Edinburgh. He recognized a variety of terraces flanking the Earn, but he arranged them broadly into three stages. Taken in ascending order, the *first* and lowest rises from 3 to

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[1] "The Geology of the Country round Blair Atholl, Pitlochry, and Aberfeldy," *Memoirs of the Geological Survey*, 1905, p. 144; *Ancient Sea Margins*, Robert Chambers.

10 feet above the river; it is often seen to spread out into an extensive haughland. The *second* terrace varies in height from 16 to 24 feet above the river; this terrace can be traced from Cultibregan for a distance of three and a-half miles down the river as far as Lennoch. The *third* terrace varies from 35 to 60 feet above the stream, and is well shown at Monzievaird, Lawers, and Tomperran. All the three terraces are also well shown at Dunning, near Kinkell Bridge, and at Dalpatrick, near Crieff.

In the lower reaches of the Earn many instructive examples of river erosion and deposition can be seen in all stages of progress. In James Knox's map of the basin of the Tay, published in 1831, a deadwater near Forgandenny station is simply marked as a curve or bend in the river. Since that time the river has crept over a very large piece of land, completing the segment into a circle and forming the present deadwater. Still further up the river another deadwater of an even larger size shows evidence of having been formed within a comparatively recent period of time.

Most of the streams in the Grampians and Strathmore, like those of the Tay valley, have one or more terraces that have been formed by the deposition of sediment. In many of the smaller streams only one such terrace is to be found; this forms the flat meadow or haugh through which the stream winds. If a careful study be made of the water-courses of the Grampians, one cannot fail to be impressed with the important part they have played in the development of the scenery. Hundreds of ravines have been dug out of either the boulder-clay or the solid rock, the materials having been carried forward and spread out in broad haughlands

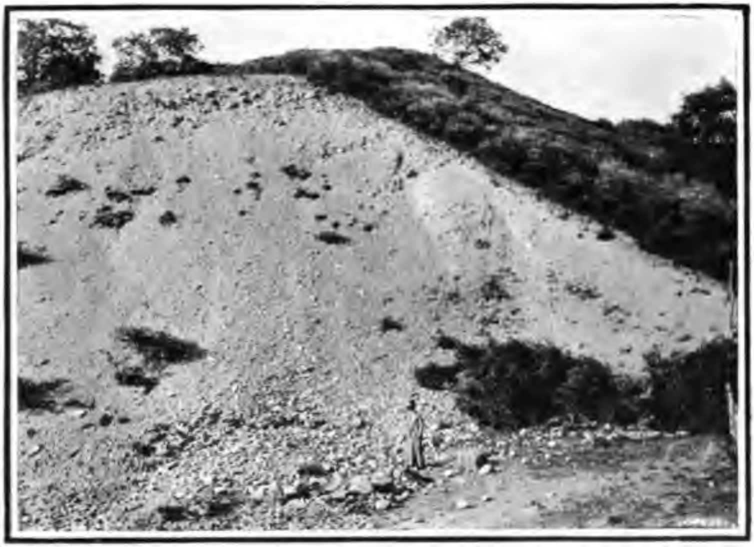

FIG. 77.—Section of Ancient Terrace at Moulinearn, showing Coarse Bedding.

Photo. by H. COATES.

over the floors of the valleys, or, in some cases, onwards to the sea.

Professor James Geikie is of the opinion that, when the terraces were formed, the rivers flowed in much larger volume than they do at present. He considers that the gravel banks—of which the terraces are built—indicate that when they were being accumulated the streams were both broader and deeper than they are now. In support of this view, he points out that the materials of the modern alluvial flats show a much more orderly arrangement than those of the older deposits. In short, he thinks that the phenomena of "valley within valley" indicates that the streams had diminished in width and had also successively reached lower levels. "The fact that the high-level post-glacial terraces have not been denuded away, but still in many places form more or less continuous plains on one or both sides of a valley sufficiently proves that the streams had formerly a much larger sectional area. And the generally coarser character of the older river-deposits is in complete accord with this view."

Sir Charles Lyell has sought to account for the formation of river-terraces by oscillations of the surface of the land. He supposes that while the rivers were eroding their beds a series of elevatory movements took place, the result being an increase in the fall and also in the velocity of the river. According to this view, periods of tranquillity were succeeded by periods of elevation. During the former the river spread out broad flats of alluvium in the manner that has been described; whereas, during a period of elevation, the erosive power of the river was increased, and it then cut its way downwards until, by reason of its fall in level, the erosive action would become less and less, and eventually would entirely cease. In this way a series of alluvial plains and terraces would be formed.

According to some geologists, all the phenomena connected with river terracing can be explained by the ordinary action of running water without having recourse to the view that the river at any time filled up its valley to the base or rim of its highest terrace. They also look upon oscillations of the surface of the land as unnecessary for the production of river terraces. Geologists who hold this view have pointed out that the miniature stream-terraces left upon a sandy sea-shore when the tide has retired, or in runnels proceeding from springs, often exhibit all the phenomena connected with curves, deflection-banks, and terraced slopes, such as are seen in our largest rivers, where the supply of water from a spring has been uniform, and all the effects of river terracing have been produced by the streamlet that flows from it. There can scarcely be any doubt that terracing in this case is perfectly compatible with a uniformity in the water supply.

Though considerable obscurity hangs over the formation of the various lakes by which water is unnaturally, as it were, kept in a state of rest above the lower level of the sea, we have little difficulty in tracing the character of those disturbing forces which have a tendency to obliterate the lake. The lakes of the Highlands have, in many instances, become the receptacles of vast quantities of alluvial material brought down by the streams. This filling-up process is continually going forward. Sand, gravel, mud, and peat are being brought down and deposited at the mouths of the streams, forming deltas. The silt formed

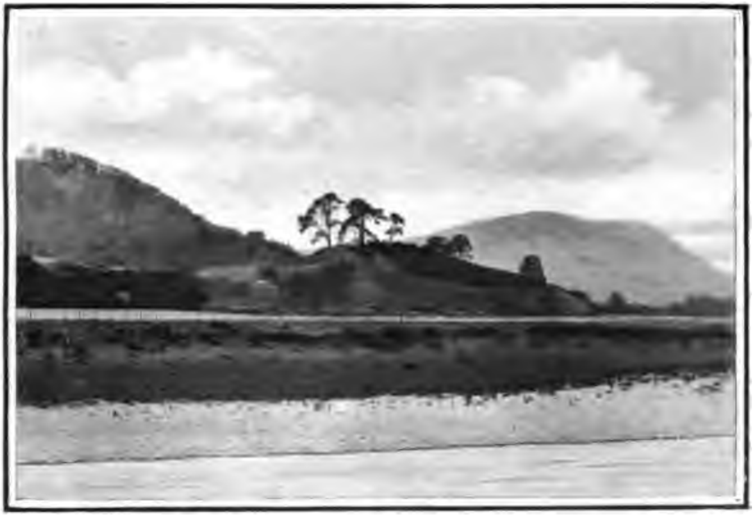

FIG. 78.—Spur of Ancient Terrace opposite Guay.

Photo. by H. COATES.

by lakes is fine, regularly and horizontally stratified, with occasional films of coarser sand, and even an occasional boulder. Most lakes present a margin or terrace, formed by the constant alteration from wet to dry, and by the constant disintegration caused by rain and frost. The materials thus broken up are acted upon by the waves during wind, which, with the under-current, has a tendency to loosen and carry out the disintegrated matter.

Many examples of lakes having been completely silted up are to be met with in the Highlands, the area once occupied by the loch being now replaced by a broad alluvial flat, through which a stream or river meanders. When a river enters a lake its current is at once checked, and a fan-shaped accumulation is formed opposite its mouth and upon the lake bottom. Where a number of streams enter a lake the different sediments brought down by each stream may overlap and inosculate with one another.

It will be found that, as a rule, the materials which have been deposited in these fresh-water lochs become finer grained the further they are traced from the shore. As has already been observed, the coarser materials are found off the mouths of rivers and burns, and in many cases they are seen to extend for long distances into the loch, reaching into rather deep water. The margins of most of the larger lakes are abundantly strewn with boulders, gravel, and sand, which have been derived from the deposits that fringe the lake by the action of the waves.

The recent bathymetrical survey of the Highland lochs has shown that the central parts of the lochs are covered by a fine impalpable mud of a light or dark-brown colour, and in some cases showing different coloured bandings. The mineral species usually present are quartz, felspar, black and white mica, amphibole, pyroxene, magnetite, garnets, etc.; with these are often associated diatoms, and fibres of vegetable material. When Loch Tay is standing at its summer level numerous patches of bright red sand may be observed all round its western shore. These patches of red sand form a striking contrast to the yellow siliceous sand which forms the main bulk of the sandy deposits of the shore. If the red sand be examined, it will be found to be composed of minute fragments of garnets, which have been derived from the epidiorites and mica-schists of the surrounding neighbourhood. These have been sifted out from the denser siliceous material owing to their lighter specific gravity.

It is not an uncommon thing to find that lakes have, in some instances, become divided into a series or chain of lakes, by the deposition of alluvial materials. This is well shown in the case of Loch Doine, Loch Voil, and Loch Lubnaig. It seems clear that within post-glacial times these three lochs must have formed one continuous sheet of water. Loch Doine has been separated from Loch Voil by two cones of alluvium; the cone on the north side of the lochs having been produced by the stream that flows down Monachyle Glen, while that on the south side has been formed by the stream that enters the loch at Monachyle Tuarach. At the head of Loch Doine there is a strip of alluvium that stretches westwards for a distance of 1½ miles; it has been formed by the Lochlarig river and its tributaries. A consideration of the soundings

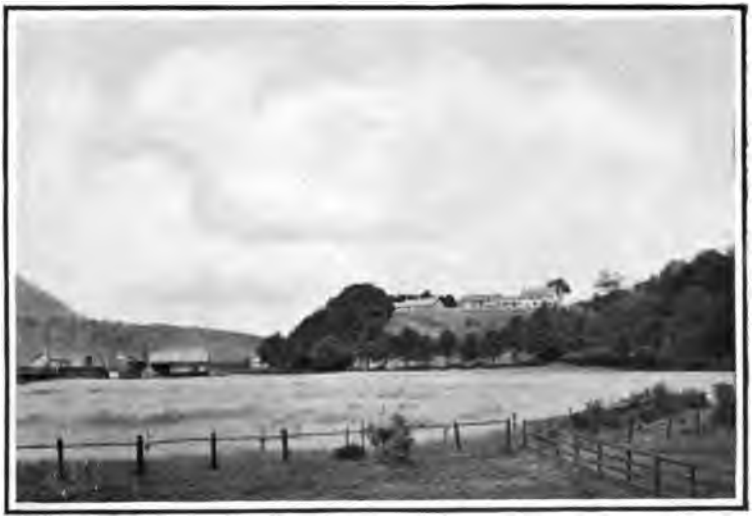

FIG. 80 - -Spur of Ancient Terrace at Dalnabo, Ballinluig, with Upper Haughland in foreground.

Photo. by H. COATES.

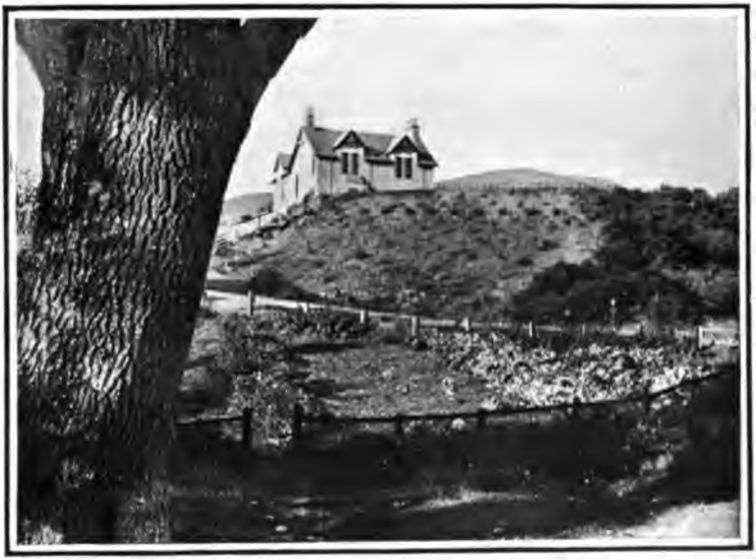

FIG. 81.—Bank of Ancient River Deposit, on the Moulin Road, Pitlochry.

Photo. by J. S. GRANT.

serves to show that Loch Doine and Loch Voil belong to the same rock basin.

Loch Voil is separated from Loch Lubnaig by a long stretch of alluvium, which has been accumulated by the streams that descend Glen Buckie, the Kirkton Glen, and the various streams that enter the Balvaig in its course through Strathyre. At the head of Loch Lubnaig the silting-up process is shown in progress by the long tongues of alluvial material that project into the loch along both sides of the Balvaig, and which have isolated small basins of fresh water from the main body of the loch.

Fig. 95 gives a view of Loch Lubnaig from Beinn an t-Shithein, and shows the delta of the Balvaig in the foreground, with the tongues of alluvial matter projecting into the loch, and the isolated basins of fresh water. In the distance is seen the great spur of Ben Ledi, which descends to the edge of the loch. This ridge is wholly composed of Ben Ledi grits with infolds of the "green beds," and it is mainly out of these rocks that the lake basin has been excavated.

Deposits of alluvial material are usually to be met with at the heads of most of the lochs where the main stream enters the loch. For instance, at the head of Loch Tay, where the Dochart and Lochay unite, there is a broad spread of alluvium, which has been deposited by these two rivers. That this alluvial material is of considerable thickness is shown by the fact that in a bore put down where the railway bridge spans the Lochay, it reached 12 fathoms without finding solid rock. A comparison of the Ordnance Survey map, made in 1861, with the present configuration of the spit at the mouth of the two rivers, shows that since that time it has been pushed ⅓ of a mile further into the loch.

Owing to the great diversity of rocks which exist within the area under notice, there is an almost equally great difference in the character of the soils. Soils are derived from rocks, and many of their most important properties can be traced to the solid rocks which underlie them. In the Highland region the schistose and granitic mountains are usually covered with heath, and are barren; this, of course, is due to their altitude, as well as to the fact that their rocky materials often lie bare to the surface over wide areas. Strips of fertile meadow-land can often be found along the borders of streams or rivers, but they are usually not of any great extent, being limited to the alluvial deposits which have been described. For this reason the Highlands may be looked upon as forming a wild pastoral country, the abode of grouse, black cattle, sheep, and red deer.

Previous to the advent of the great Ice Age, there must have been a long-continued period of subaerial denudation. For countless ages the rocks were being subjected to chemical and mechanical action, and as a result of this the old land surface was buried under a vast pile of superficial débris. When the ice sheet first swept across the country it would have a great quantity of material ready to hand, which would be carried onwards and deposited as the ground-moraine or boulder-clay. In this way a superficial covering, consisting of materials more or less foreign to the district in which they occur, would be found resting upon the older rocks. In the chapter previous to this we have shown that the valley of Strathmore is

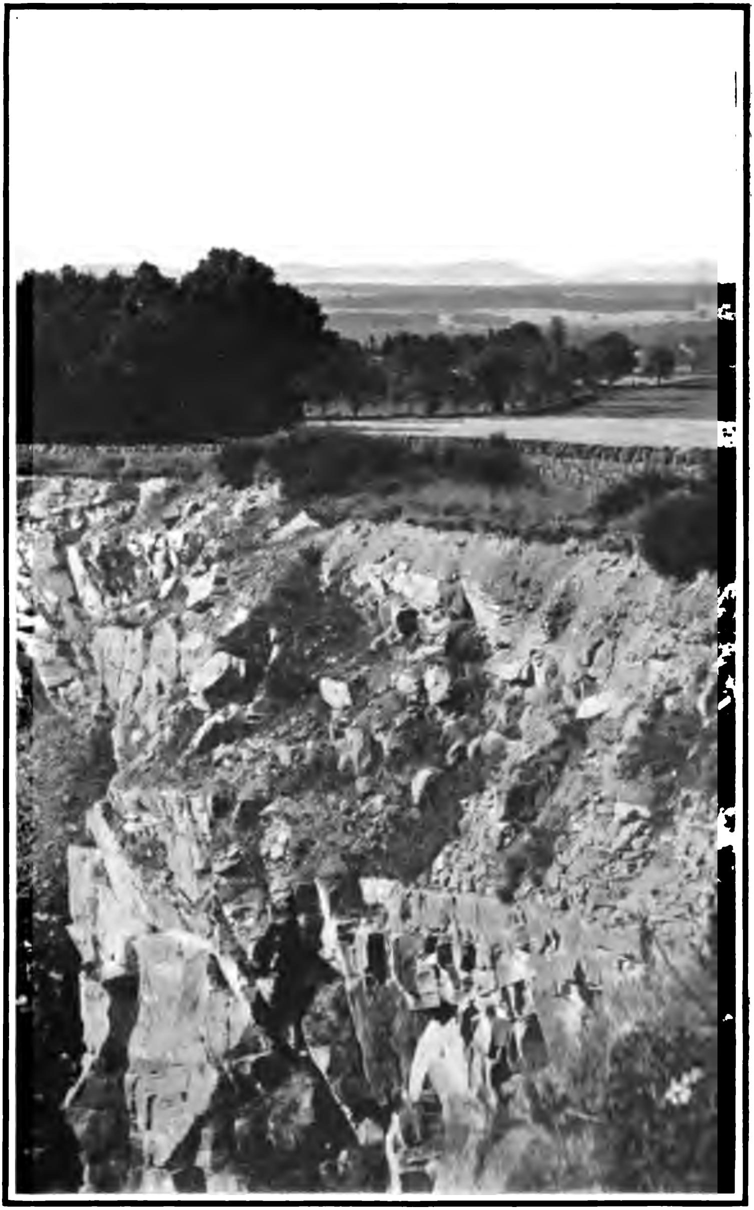

FIG. 82.—Section at Burghmuir Quarry, near Perth, showing Old Red Sandstone, with Brash, Sub-Soil, Soil, and Vegetation above. Strathmore and the Grampians in the distance.

Photo. by H. COATES.

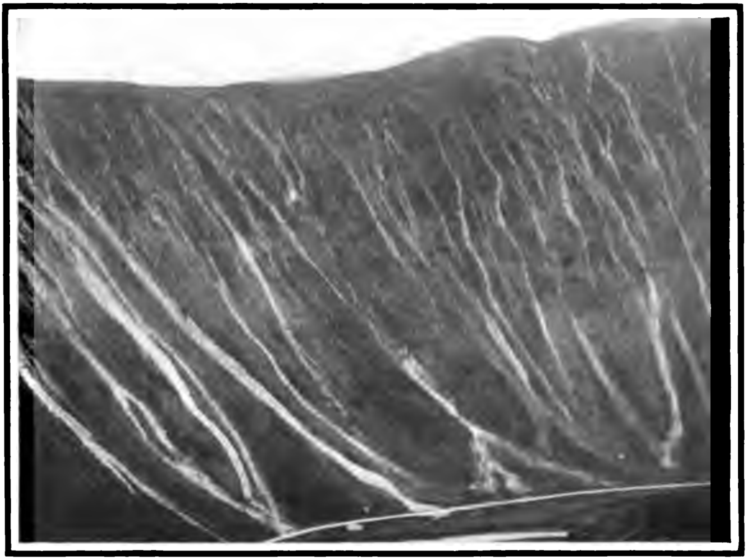

FIG. 83.—Rain Gullies on the side of the Sma' Glen, made by a Cloud-burst on August 22, 1900.

Photo. by A. S. REID, M.A., F.G.S.

covered with a thick deposit of boulder-clay, the materials of which have been derived, to a great extent, from the schists of the Highlands. In a similar manner the Ochils and Sidlaws have been covered by a deposit of boulder-clay, which has been largely derived from the Old Red Sandstone Rocks of the valley of Strathmore. It will be seen, then, that the vegetable soils are not directly derived from the underlying solid rocks, and that soils of different characters may overlie the same geological formation. The boulder-clay, then, is an important factor in determining the nature of the soil, and ought always to be taken into account when the source from which the soils have been derived is under consideration. Leaving this aspect of the question out of consideration in the meantime, we may note that, in the Highland portion of the region under notice, the soils have been largely derived from the crystalline schists, and are, to a large extent, arenaceous or sandy, rather than argillaceous or clayey. They are usually of no great depth, and in a dry season suffer from a lack of sufficient underground moisture. The most valuable soil in the Highland area is the haugh soil of fine alluvium which occurs in the river valleys, such as can be seen around Killin, in various parts of Glen Dochart, Strath Fillan, and in other glens in various parts of the district.

In the great valley of Strathmore the arenaceous element also predominates to a great extent in the composition of the soils. There is, however, a greater proportion of peroxide of iron in the soil, and it is usually richer and deeper than in the Highland area. The alluvial deposits of the rivers have also stretched over wider areas than in the Highlands. A thick bed of stiff clay forms a flat tract, extending for over eighteen miles along the Forth, from Bridge of Allan to Gartmore Bridge. A similar bed of clay covers by far the larger part of the Carse of Gowrie. The slopes of the volcanic hills, such as the Sidlaws and Ochils, are covered by soils rich in soda, potash, and magnesia, which have been derived from the disintegration of the volcanic rocks.

Extensive deposits of peat are to be met with both in the Highlands and Strathmore. They have been formed by the annual growth and decay of vegetable material. The mosses are the most important peat-forming plants, and mostly belong to the genus *Sphagnum*. The stems of the bog moss wither and die, while the upper portion of the plant continues to flourish ; and in this way it may gradually form a bed of great thickness. The roots and stems of other plants also contribute to the accumulating bed, forming a tangled mass, which holds water like a sponge, and this constitutes a favourable soil for the growth of the moss above. During floods muddy water may be washed into the moss. Dust may also be blown over the marsh by winds ; this helps to consolidate the felted mass, and a deposit of considerable firmness is produced.

In the deeper and older parts of a peat-bog the moss is more or less compacted, owing to the superincumbent pressure ; it then takes the form of a brownish-black felt-like or almost compact mass. On the slopes of mountains and on moorlands the peat rarely reaches more than a foot in thickness, and is generally of an incoherent texture. The plants which

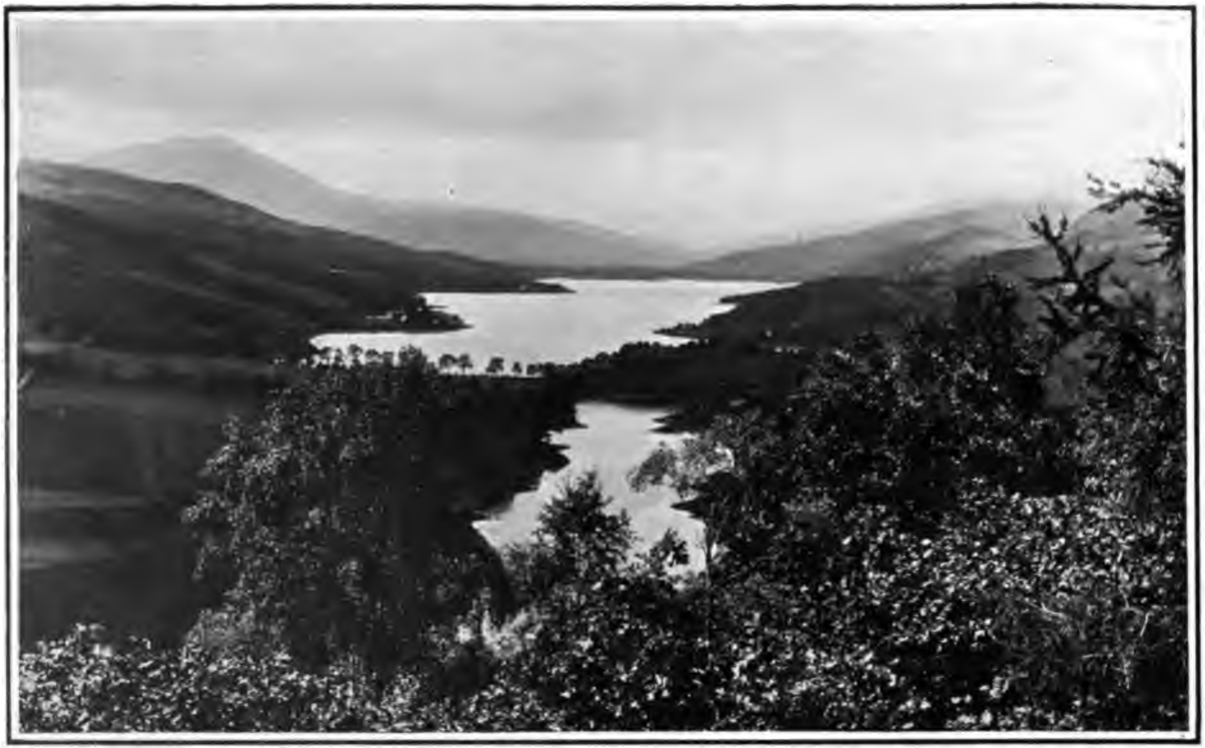

Fig. 84.—Loch Tummel, from the Queen's View.

Photo. by Wm. Ellison.

form it are usually the heaths and rushes which grow in such situations.

Forest peat is characterized by its flaky texture, and this structure may often be recognized, though there may be no roots or fragments of trees present. When trees are present they are usually oak, Scotch fir, birch, hazel, and alder; along with these there may occur fragments of the plants which grew under their shade, or which have arisen upon the swampy ground which has followed the destruction of the wood or forest. In many instances, great thicknesses of peat have been accumulated in boggy marshes or upon the sites of silted-up lakes. This type of peat is noted both for its depth and extent, and it includes some of the largest tracts which have been brought into cultivation.

CHAPTER XV

THE SCENERY OF THE GRAMPIANS AND STRATHMORE IN RELATION TO THEIR GEOLOGICAL STRUCTURE

Can thy style-discerning eye
The hidden working Builder spy,
Who builds, yet makes no chips, no din,
With hammer soft as snowflake's flight;—
Knowest thou this?
O pilgrim, wandering not amiss!
Already my rocks lie light,
And soon my cone will spin.

EMERSON.

IN the preceding chapters of this work, we have approached our subject analytically. In this, the concluding chapter, we propose to look at it from the synthetic standpoint, attempting to translate into history the great succession of events as they are chronicled in the rocks of the Grampians and Strathmore, and also showing how the present configuration of the surface, or the scenery, of this area has been gradually evolved during geological time.

In the chapters dealing with the rocks of the Highlands, we have shown that the rocks forming these great mountain masses are to a large extent of fragmental origin, having been formed in much the same

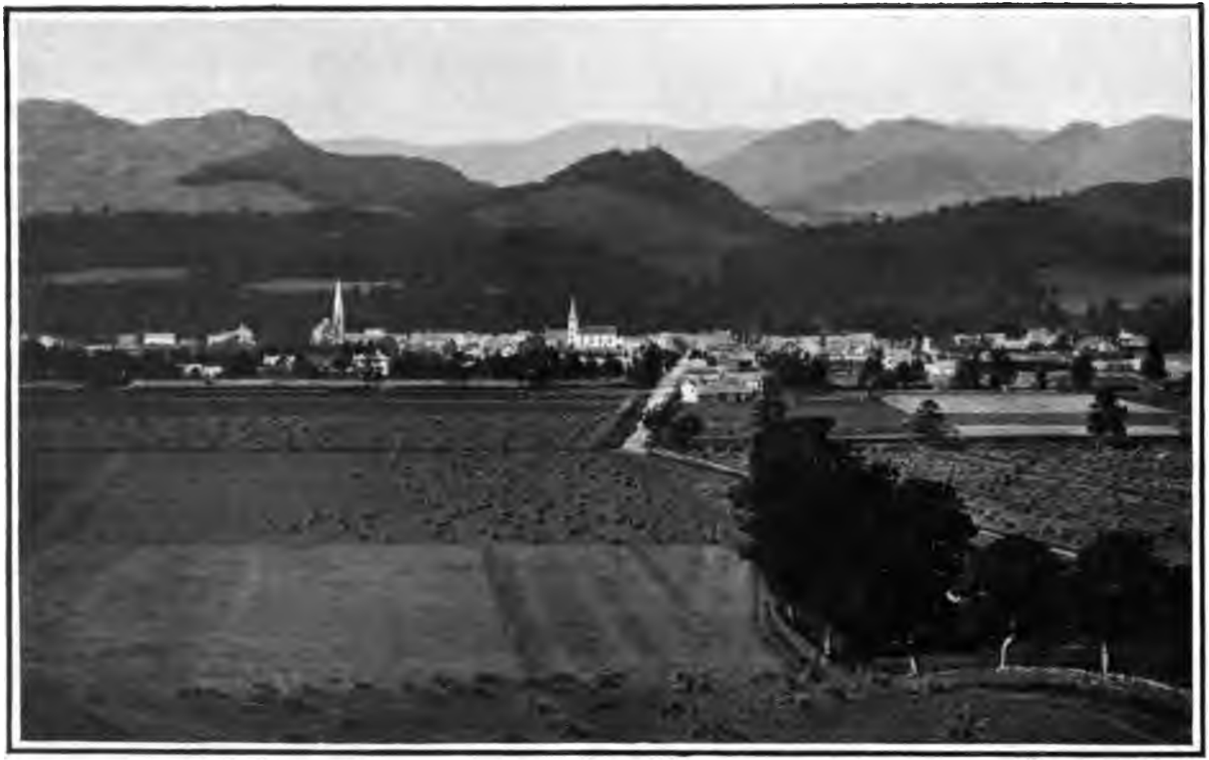

Fig. 85.—Village of Comrie, with Strathmore in the foreground, and Foot-hills and Grampians in the distance.

Photo. by G. W. Wilson & Co., Aberdeen.

manner as sands and muds are being accumulated along the sea-shore at the present day. During the processes of mountain-building, these ancient sediments have been subjected to intense crushing, and new structures and new minerals have been developed in them, so that they no longer split along their original bedding planes, but along secondary planes of cleavage and foliation.

After the formation of the Grampian geosynclinal, in which the different beds which are found in the Highlands were accumulated, these were ridged up so as to form the Grampian geanticlinal. It seems to us that a careful study of this ancient mountain chain preserved in the Scottish Highlands points to the conclusion that the great central massive must have risen over what is now the Midland Valley, and that the Ben Lawers anticlinorium was but a subsidiary elevation compared with this great central *Fächer.* The greater part of this massive has, of course, been carried down between the boundary faults which separate the Midland Valley from the Highlands and Southern Uplands, and lies concealed below the mantle of younger Palaeozoic rocks, which lie between these two boundary faults. Along the shores of the Firth of Clyde we catch a glimpse of the northern limb of this massive. We have already pointed out that to the east of Ben Lomond the rocks along the frontier Highlands generally dip to the north-west. Between Loch Ard and Loch Lomond the beds are almost vertical, or the dips vary ; while from Luss, down into Cowal, Bute, and Arran, the beds dip at high angles towards the south-east.

Between Loch Lomond and Loch Lubnaig the schists are traversed by a series of cross faults, which emerge from the great boundary fault. They are of pre-Old Red Sandstone age, and strike north-east and south-west. As a rule, the western portion has been displaced towards the south, *e.g.* the downthrow is to the west. Perhaps the most important of these is the Loch Tay fault, which has been traced from Aberfoyle by Loch Lubnaig, Loch Earn, and Loch Tay to Blair Atholl and Glen Tilt. Further west, and running in an almost parallel direction with the Loch Tay fault, there is another line of disruption, which has been traced from the Braes of Balquhidder across the river Dochart, near Luib. From this point, it crosses the ridge that separates Glen Dochart and Glen Lochay, entering the latter glen near Corrycharmaig. In this part of its course it crosses the Ben Lawers anticlinorium. From Glen Lochay, it has been traced north-eastwards to Loch Rannoch and Loch Garry. Still further west, another of these dislocations has been traced from the head of Loch Fyne north-eastwards in the direction of Tyndrum, Loch Lyon, and the west end of Loch Rannoch, to Loch Ericht. These larger faults are accompanied by a series of minor dislocations, which run in a roughly parallel direction with the larger faults.

Generally speaking, then, to the east of these lines of dislocation, and along the frontier Highlands, the beds dip towards the north-west, while to the west of them they dip to the south-east, our interpretation of this structure being that, during the ridging up of the Grampian geanticlinal, two well-defined anticlinoria were developed, the axis of the larger and more important of these running along what is now the centre of the Midland Valley, while the second is seen

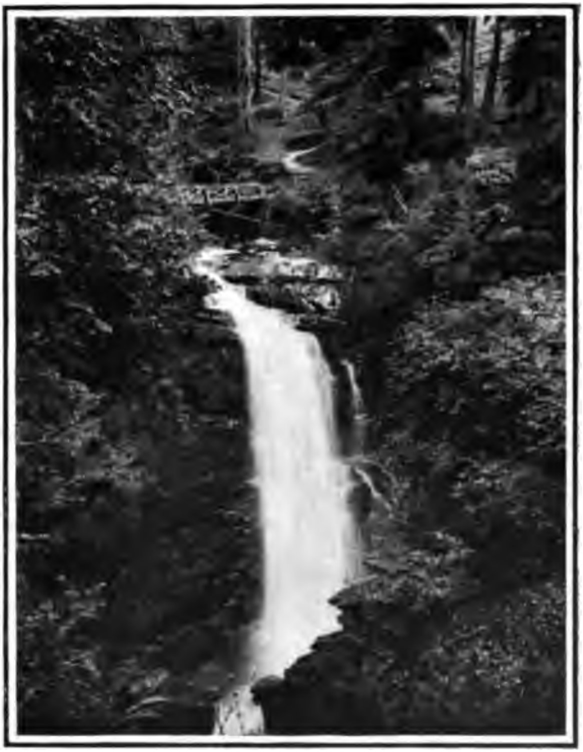

FIG. 86.—Upper Fall of Moness, Aberfeldy.

Photo. by J. S. GRANT.

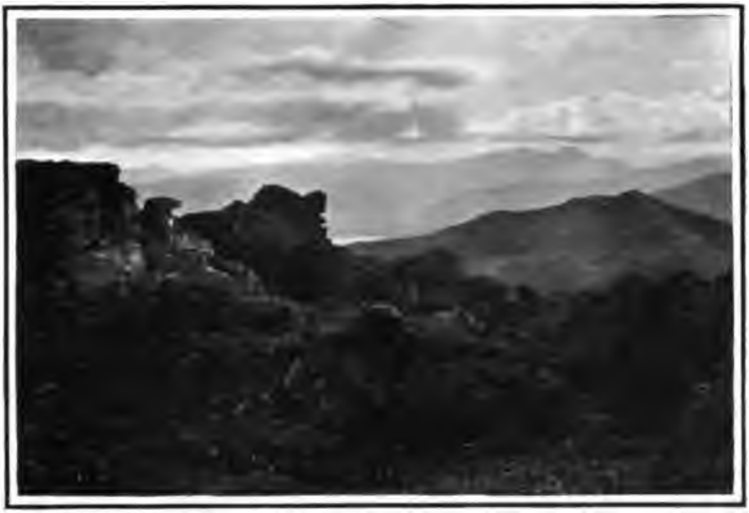

FIG. 87.—View from the Summit of Ben Lawers.

Photo. by W. LAMOND HOWIE, F.C.S.

in the Ben Lawers anticlinorium. Between these two anticlinoria, a synclinorium must have been developed. The position of this is shown in the axis of folding that runs down the centre of Cowal.

The axis of the Cowal synclinorium can be traced through the peninsula of Kintyre, whence it crosses to Port a' Mhadaidh, on Loch Fyne. From this point it runs by the heads of Loch Riddon, Loch Striven, Loch Eck, Loch Goil, and Loch Long, terminating on the shores of Loch Lomond at Tarbet. To the east of Loch Lomond the structure of the ground appears to be more complex. This is partly accounted for by the numerous cross faults, or lateral wrenches, which we have described as occurring in this area, these faults tending to break up and destroy the continuity of the axis of folding, by shifting the outcrops of the schist zones on the west side successively towards the south.

Further, it appears that in the ridging up of these two anticlinoria their axes were driven much closer together towards the west of the mountain chain than in the east. An examination of a geological map of Scotland, or even a topographical map, will show this very clearly. Thus, the lines of the Southern Upland boundary fault, the Highland boundary fault, the axis of the Cowal synclinorium, and the Ben Lawers anticlinorium, the fault which runs along the Great Glen, and the overthrusts of the North-West Highlands, appear to radiate like the spokes of a wheel from a centre, situated somewhere in the north of Ireland (see Sketch Map, Fig. 88).

This structure is made exceedingly clear by the comparison of a section, taken across the western part of the chain, with one taken across the eastern. Such a

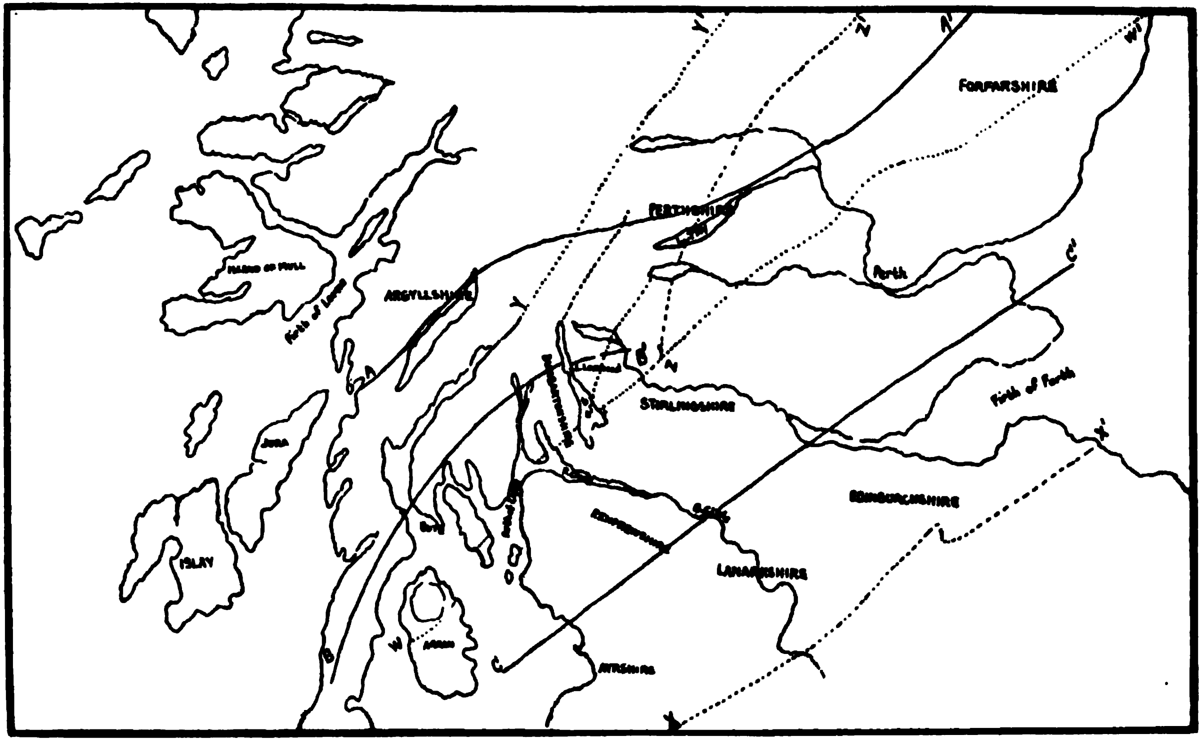

FIG. 88.—SKETCH MAP TO SHOW THE POSITION OF THE GREAT AXIAL LINES OF FOLDING AND THE PRINCIPAL FAULTS.
*AA*¹ Ben Lawers Anticlinorium. *BB*¹ Cowal Synclinorium. *CC*¹ Axis of supposed Great Central Massive or Anticlinorium.
*WW*¹ Highland Boundary Fault. *XX*¹ Southern Upland Boundary Fault. *YY*¹ Tyndrum Cross Fault. *ZZ*¹ Loch Tay Cross Fault.

section as that which has already been described across Cowal shows that the beds, which constitute the Cowal synclinorium, have been much more closely compressed, and have suffered a more intense dynamic metamorphism, than the strata which occupy a similar tectonic position farther to the east in Perthshire.

In a word, it seems that when traced from east to west the two anticlinoria have been driven closer and closer together, till, in the region of Loch Lomond, inversion of the strata, accompanied by the great lateral wrenches, has taken place, and has thus ushered in still further to the west, and along the shores of the Firth of Clyde, the northern limb of the great central massive.

The experimental researches that have been made in mountain-building show that, by continued compression of the strata, a simple anticline may be made to pass eventually into a "fan-shaped" structure, consisting of a complex series of isoclinal folds. By a continuation of the pressure, the underlying and oldest strata are made to come into the core of the "fan-structure," and a strong tendency to the development of thrust planes on each side of it takes place.

It seems to us that the great central massive that rose over what is now the Midland Valley must have belonged to that type of "fan-shaped" structure which is produced by intense compression. The evidence derived from the sections exposed along the western shores of the Firth of Clyde shows that the oldest rocks in the Highland series have been successively brought into the core of this "fan-shaped" structure, and we have come to the conclusion that the two great boundary faults, though now of the nature of normal trough faults, were originally developed along the flanks of the " fan " by the intense lateral compression to which it was subjected.

It is somewhat interesting to note in this connection that some of the Upper Silurian inliers, which appear to the north of the boundary fault in Lanarkshire, are truncated by reversed faults, which hade in a parallel direction with the boundary fault, the northern limb, consisting of the older strata, having been driven over the southern limb of younger strata.

So far, then, we have discussed the first two great stages in the geological history of the area under consideration, namely, the deposition of the sediments which form the mountain masses of the Highlands, and their upheaval into a true mountain chain of elevation, whose general configuration we have attempted to restore. The third stage brings us back again, in the cycle of change which a land surface is ever undergoing, to a period of marine and subaerial denudation, and we find this ancient mountain chain being submerged below the sea, which has levelled it down to a great platform of marine erosion and buried it beneath a mass of its own ruins.

It seems highly probable that this period of marine denudation began with the deposition of the Torridon Sandstones of the North-West Highlands, and was continued during Cambrian times, the north-west side of the ancient continent having been submerged during the deposition of these rocks.

Whether the south-east side of the chain was submerged during these periods, we cannot say. The absence of these formations in the south of Scotland seems rather to indicate that, during Cambrian and

Torridonian times, it was a land surface. With the beginning of the Ordovician period, the ancient mountain chain was attacked from the south-east, and a continuously overlapping series of Ordovician, Silurian, Devonian, and Carboniferous deposits was accumulated upon it. Probably towards the close of the Palaeozoic period what is now the area occupied by the Midland Valley became depressed between the great boundary faults, and this sunken district became the site of important and long-continued igneous phenomena. A very large part of the area is now covered by lavas which have been poured out upon the surface; and by huge sills and bosses of igneous rock, that have invaded the sedimentary strata; while in the plutonic rocks of the Southern Highlands we have the deep-seated equivalents of the volcanic rocks of the Midland Valley.

The problem, then, of the evolution of the Highland valley systems resolves itself into the following conditions: Towards the close of the Carboniferous period, and to the north of the Highland boundary fault, there lay a platform of highly convoluted crystalline schists, buried beneath a thick mantle of Old Red Sandstone and Carboniferous rocks, which lay upon the schists with a gentle slope towards the south-east. To the south of the Highland boundary fault, and between it and the southern upland boundary fault, the younger Palaeozoic rocks, as has been pointed out, were folded into a series of anticlines and synclines whose axes ran parallel with the strike of the Highland schists, and with the boundary faults (see Fig. 89).

In the chapter dealing with the physiography of the area, we have shown that the valley systems of the

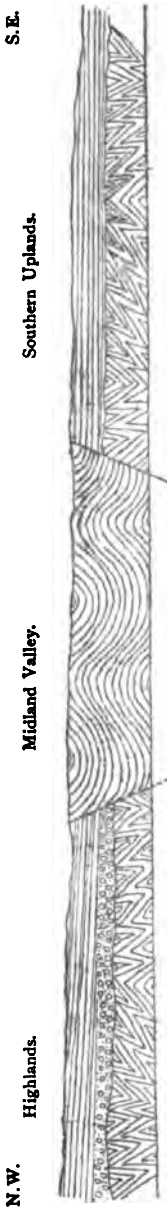

FIG. 89.—Diagrammatic Section through the Highlands, the Midland Valley, and the Southern Uplands of Scotland, showing the Boundary Faults.

Highlands can be classified into two types, the transverse and the longitudinal, the former having a general north-west and south-east trend, and the latter running in a north-east and south-west direction. The transverse valleys, such as the Isla, the Shee, the Ardle, the Garry, the Tay from Ballinluig to Perth, and those lying to the west of the Tay Valley, must have had their initial direction given to them by the slope of the plane of marine denudation towards the south-east, or, rather, by the slope of the beds of younger deposits which lay upon it in that direction. An inspection of Fig. 89 will make this clearer.

These transverse streams, as they began to descend this slope, would cut into the hard and soft rocks alike, and after they had cut through the overlying Old Red Sandstone rocks and reached the schists, there would be a strong tendency for them to keep the courses which they had already established. The principal features of our Scottish valley systems were thus sketched out at an early period in geological time,

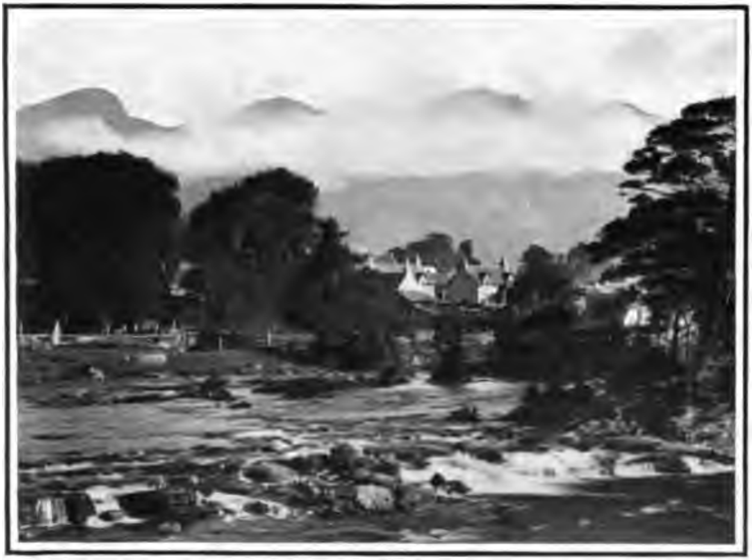

FIG. 90.—The Killin Hills, from the Dochart.

Photo. by W. LAMOND HOWIE, F.C.S.

and were determined by factors, all evidence of which has now disappeared from the Perthshire Highlands.

The water falling upon the sides of these transverse valleys would tend to form tributary streams, running in a direction parallel to the general strike of the rocks. An increase in the rain conveyed by these lateral streams into the transverse valleys would eventually cut out such deep longitudinal trenches as the valley of the Tay from Ballinluig to the head of Glen Dochart, the valley of Loch Ericht, and the valleys of Loch Voil and Loch Earn. The scooping out of the longitudinal valleys would, of course, be contemporaneous with those belonging to the transverse type. When they reached the underlying platform of schists their direction would be determined to a large extent by the character of the schists. Thus, it seems quite possible that the present position of the Tay valley, from Ballinluig to the head of Glen Dochart, may be accounted for by supposing that, after the tributary stream had reached the underlying platform of schists, it found it easier to cut along the outcrop of the Upper Argillaceous Zone than along the more siliceous and harder beds which occur both above and below it (Fig. 93).

This view of the origin of the longitudinal part of the Tay valley in its Highland course seems to us to gain some support from the fact that there is an almost continuous outcrop of the different members of the Upper Argillaceous Zone, from Pitlochry in the east to Strath Fillan in the west, the outcrop running parallel with the present course of the Tay valley at an average distance of about four miles to the north-west of it.

Further to the west the deep longitudinal valley of Loch Fyne, which looks like a south-westerly prolongation of the Tay valley, actually coincides with the Upper Argillaceous Zone, and thus helps to confirm the view that the longitudinal part of the Tay valley, from Ballinluig to Glen Dochart, may have been determined by its original coincidence with these softer rocks, and that, once this direction was given to it, the stream would continue to keep it, notwithstanding the fact that the underlying rocks were harder. It ought, of course, to be kept in mind that, when the tributary stream began to cut into the schists, the outcrop of the Upper Argillaceous Zone would be some four miles to the south of its present outcrop, a condition which is supported by the structure of this area, which we described in a former part of this work.

So far, then, we have accounted for the Highland portion of the Tay valley. It now remains for us to inquire into the geological factors which have determined its lowland course from Dunkeld to the sea. To the south of Dunkeld the Tay crosses the great boundary fault and enters upon its course over the Old Red Sandstone (see Fig. 1 and Frontispiece). As far as Perth the river keeps the transverse course originally imparted to it in its descent over the Highland rocks, but below Perth it is bent round almost at right angles to its former course, and passes out to the sea between the volcanic rocks of the Sidlaws on the north, and those of the Ochils on the south (see Fig. 52).

At a first glance it seems exceedingly strange that the river, after crossing from the Highland schists

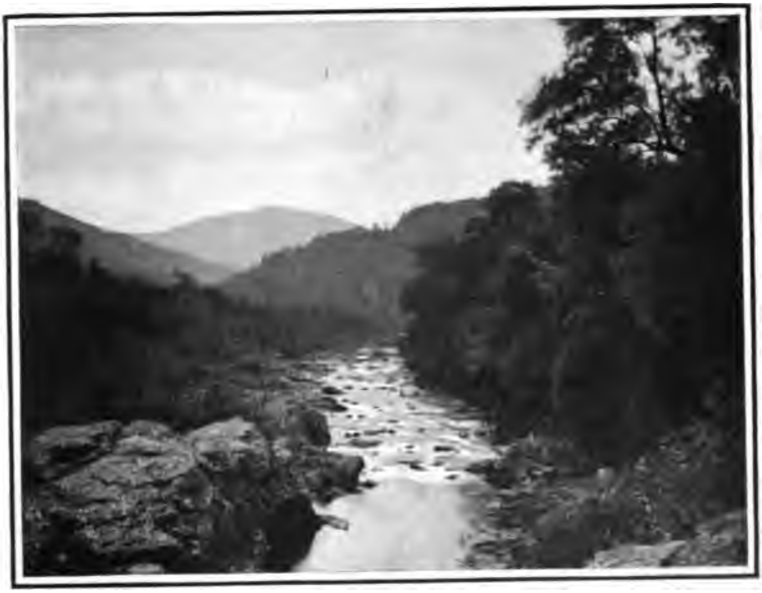

FIG. 91.—Glen Lyon.

Photo. by WM. ELLISON.

to the Old Red Sandstone, should prefer to reach the sea by way of the anticlinal arch of hard volcanic rocks, rather than by the syncline of soft sandstone which lies in the broad valley of Strathmore (see Fig. 10). We have already shown that a trough fault passes along the Carse of Gowrie and the Firth of Tay. The northern line of fault is seen along the southern front of Moncrieff Hill, and it crosses the Tay somewhere about the back of Inchyra, running along the foot of the Sidlaw Hills towards Pitroddie and Kinnaird, and thence eastwards towards Dundee. The southern line of fault runs in a parallel direction, extending from Glenearn, along by Dron and Abernethy, and thence to Newburgh (see Sketch Map). The effect of this fault has been, as before stated, to bring down into the very heart of the Lower Old Red Sandstone rocks the Upper Old Red Sandstone Series, and even, in some cases, as at Dron, the basement beds of the Carboniferous Series. This trough fault has had a most important influence on the topography of the district, for it has carried down the hard volcanic rocks, and presented to the surface the softer overlying sandstones of the Upper Old Red and Lower Carboniferous Series, which have been more easily worn away than the volcanic rocks forming the sides of the trough, and have thus given rise to the present valley of the Tay below Perth.

The short section of the river's course from Perth to Inchyra is the most difficult of any to account for. In trying to solve the problem the first question which meets us is, why did the river cut a channel for itself between Kinnoull Hill and Moncrieff Hill, instead of taking the easier course round the latter, which really forms the south-western termination of the Sidlaw range of hills? If we suppose some initial cause, which would tend to develop a channel between these two hills, then the river would naturally adopt such a course as being the most direct. From the structure of Kinnoull Hill, it is evident that the hard beds of andesite lava, which form its upper surface, must at one time have been continued across the valley of the Tay at this point, and have overlaid the beds of Moncrieff Hill. But underneath these hard beds occur more friable beds of volcanic conglomerate and tuff. Now, if we suppose that the upper hard beds of andesite became fractured during the folding of these rocks into their present anticlinal arch, then an opening would be effected in the barrier of hard strata, and the softer underlying strata would be exposed to the action of erosion. The correctness of such an explanation would, of course, be proved, if we could discover a fault at the point where the river passes between the two hills. So far as we are aware, no fault has been traced just in the course of the river, but the presence of two faults at a short distance on either side—at Cargill Wood and at Lairwell—shows that the faults in this locality run in the directions we have supposed.

To the east of the Tay valley other transverse streams, such as the Ardle and the Shee, which unite to form the Ericht, descend from the Highland schists and cross the boundary fault. The Isla, about five miles to the south-east of Alyth, bends round at right angles to its former course and, entering a longitudinal valley, flows parallel with the syncline of Old Red Sandstone

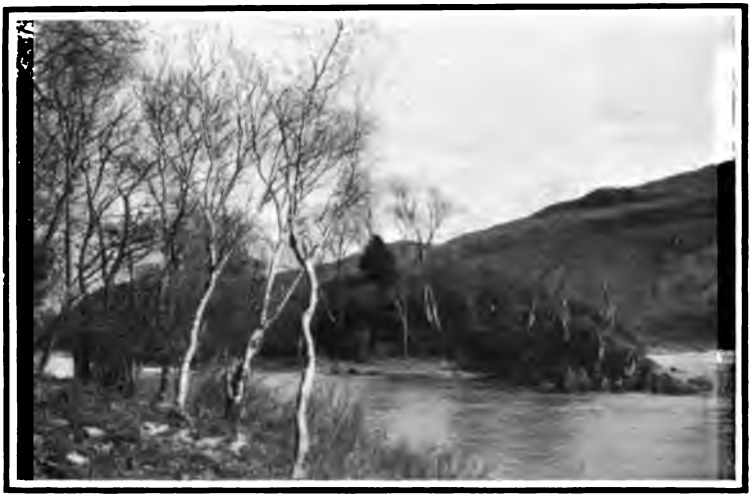

FIG. 92.—Entrance to The Narrows, Loch Ard.

Photo. by A. S. REID, M.A., F.G.S.

rocks, catching up in its course the waters of the Ericht, and joining the Tay a little to the north of Cargill. These valleys have evidently had a similar origin to that of the Tay, and may be explained in a similar manner.

Turning now to a consideration of the basin of the Forth, we find in the River Balvaig and Loch Lubnaig a valley of the transverse type. We think that Glen Gyle, Loch Katrine, Loch Chon, and Loch Ard may be placed under the same category; while in the river Lochlarig and Loch Voil we have a valley of the longitudinal type, these apparently being westerly prolongations of the valley of Loch Earn (see Fig. 67).

The transverse valleys seem to be older than the longitudinal ones. Thus, the valley of the Almond at an early period in its history probably crossed the deep trench of Loch Tay, its course being indicated by Glen Chilleine and the Lawers Burn. Further to the west similar transverse valleys, such as Glen Lednock and Glen Ogle, show evidence of having been prolonged northwards across the longitudinal valley of the Tay.

Mr. H. M. Cadell has shown that, to the west of Loch Lomond, and in Cowal and Dumbartonshire, quite a number of the large transverse valleys are often continued across watersheds, as for example, the upper part of Loch Eck and Glen Finart. In other cases they cross both low watersheds and valleys, which run in different directions, as the Inveruglas Water and the Arklet Water. He thinks that "before Loch Lomond and Loch Long came into existence, all the country east of Inveraray and northwards to the Arrochar Highlands and Glen Falloch was probably drained by the Forth, and not, as at present, by the Clyde," the watershed between the east and west coasts of Scotland being at that time a tract of ground in the neighbourhood of Loch Fyne. He also thinks that the longitudinal valley of Loch Fyne is of more recent origin than those of the Gare Loch and Loch Goil, and suggests that it may have been excavated by ice during the glacial period.

Such, then, appear to have been the principal factors which have determined the outstanding physiographical features of the Grampians, and it will be seen that there are but few instances in which the origin of a valley can be directly traced to the occurrence of a fault. It has also been pointed out that the transverse valleys have quite a different trend from the longitudinal or cross faults. A notable exception to this is, of course, the valley of the Tay, from below Perth to Dundee, which has been determined by two faults running parallel with the strike of the rocks. The straight, narrow valley of Glen Ample, at the head of Loch Earn, and its apparent continuation to the north in Glen Beich, are undoubtedly owing to the Loch Tay fault, which passes along them, and in Glen Ample brings the hard grits of Ben Vorlich on the east against the softer schists on the west (see Fig. 95).

Having thus indicated what we consider to have been the principal factors that have determined the main topography of the Grampians and the valley of Strathmore, we now turn to a consideration of some of the details of the scenery. Much of the most picturesque scenery of the southern Grampians is due to the varying character of the different schist zones which traverse that region; and for this reason it will readily be seen that the transverse valleys present a

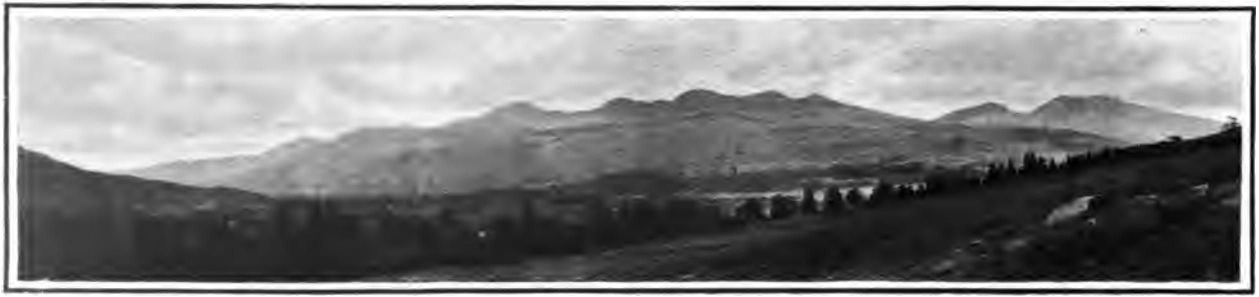

FIG. 93.—View of the Mountains to the North of Loch Tay, from Killin.

Photo. by J. W. REOCH.

greater variety of scenery than the longitudinal ones, as they cross the outcrops of the different schist zones. Along the Highland frontier the clay-slates and phyllites of the Lower Arenaceous Zone form hills of a smooth, undulating character. This is due to the comparative ease with which the slates break up and crumble into fine fragments under the influence of the weather.

Behind this narrow strip of clay-slates comes the broad band of rocks belonging to the Lower Arenaceous Zone, which consists of grits, greywackes, and conglomerates. The bold, rugged outlines of the mountains lying within this belt form a striking contrast to those of the clay-slate region. This is accounted for by the hard character of the grits, greywackes, and conglomerates, which offer a stubborn resistance to the action of the denuding agents. The consequence of this is that the scenery of this region is generally wild and rugged, the mountain sides often presenting gnarled and craggy precipices of naked rock. When dealing with the structure of the metamorphic rocks it was shown that, as a rule, schistosity is much less perfectly developed in the arenaceous rocks than in those of an argillaceous character, and the degree of roughness of the different outcrops seems to be largely dependent upon this feature. When the rocks are less schistose the outcrops are much more prominent. When schistosity is more perfectly developed they do not form such striking features in the landscape. The reason for this is that in the more highly schistose rocks, the divisional planes being more numerous, they afford a ready entrance to water and other decomposing agents, and in this way their disintegration becomes much easier, and consequently much more rapid.

If we trace upon a map the outcrop of the Lower Arenaceous Zone in the southern Grampians we shall find that much of the wildest and most characteristic scenery of that region is situated upon it. Beginning on the west, at the shores of Loch Fyne, it passes through Cowal, then crosses the Holy Loch and Loch Goil. The rugged mountains which form Argyll's Bowling Green, and those which cluster round the head of Loch Long, also lie upon it. To the east of Loch Lomond it rises into such heights as Ben Lomond, Ben A'an, Ben Venue, and Ben Ledi, and to the south of Loch Earn it forms the great range of Stuc a' Chroin and Ben Vorlich.

The general scenic character of the region under notice is typically developed in the Trossachs, and the district round the east end of Loch Katrine (see Figs. 53 and 55, vol. i.). Here the rocks consist of massive grits, which form the rocky barrier surrounding the outlet of Loch Katrine. They are well seen on the sides of Ben Venue, which springs from the verge of the loch in a series of lofty precipices, with its summit lost in the clouds, and its base stretching along the margin of the water in a magnificent perspective of bays, precipices, promontories, rocks, and trees. The hills which surround the east end of Loch Earn consist of the same rocks as those just described, and the scenic features present a striking resemblance to those seen at the extremity of Loch Katrine. The rugged character of this belt of rocks is heightened by the contrast which it makes with the soft, undulating outlines of the clay-slate region, which

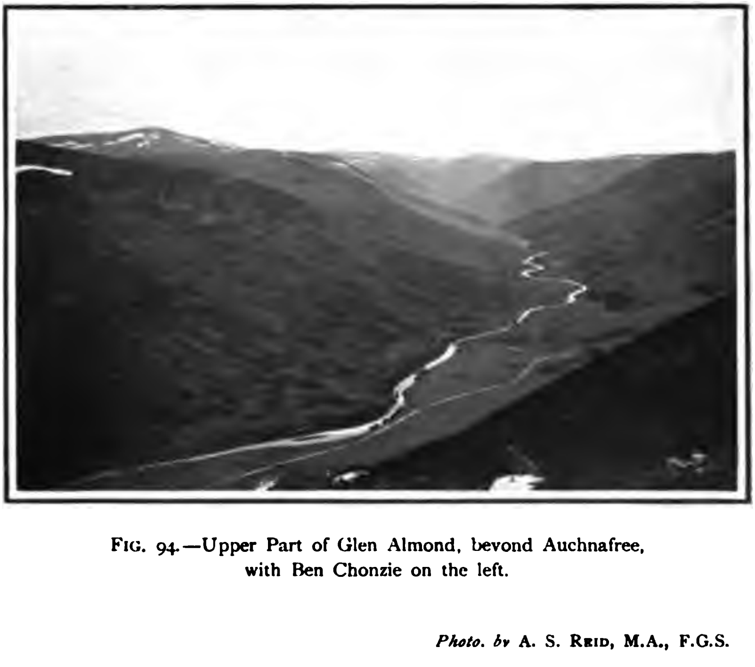

FIG. 94.—Upper Part of Glen Almond, beyond Auchnafree, with Ben Chonzie on the left.

Photo. by A. S. REID, M.A., F.G.S.

runs along its southern flanks. The scenic character of the frontier Highlands is well shown in Fig. 85, which shows Strathmore and the village of Comrie in the foreground, and the foot-hills and Grampians in the distance. Across the foreground passes the great boundary fault, while the hills immediately behind the village are formed of clay-slate. Beyond these rise the rugged outlines of Crappich Hill, Creag Bhalg, and Ben Liath, all of which consist of the grits and greywackes of the Lower Arenaceous Zone.

As we sail down the Firth of Clyde, we cannot help observing the smooth outline of the hills in the immediate foreground, such as rise above Dunoon, Blairmore, and Inellan. But if we look up the Holy Loch or Loch Long, towards the centre of Cowal, we are at once struck with the rough and jagged outline of the mountains as seen against the skyline. Mr. Clough has pointed out that this striking contrast in the scenery may be due to various causes. The rougher area coincides with the great axial line of folding which has been described as the Cowal synclinorium, and there can be no doubt that the highly altered and crumpled character of the schists along this line has to a large extent determined the rugged character of the scenery. It should also be borne in mind that the higher summits are free from drift, and as it is only these portions of the mountains that can be seen from the distance, this will also help to accentuate their wild appearance. On the other hand, the hills in the foreground can be seen from top to bottom, and the eye is at once arrested by their drift-covered slopes. It is also possible that the glaciation of the lower ground along the edges of the firth would be more intense than the more highly elevated regions of central Cowal.

The scenery associated with the garnetiferous schists and Ben Lawers phyllites is often picturesque and grand, and may be well studied in the lofty ridge to the north of Loch Tay. If the reader will turn to Fig. 93 he will see at a glance the scenic character of this region. On the left of the picture Sron Clachan slopes downward into Loch Tay, and forms the dividing ridge between Glen Dochart and Glen Lochay. In the distance, the first peak on the left is Meall Ghaordie; this is succeeded to the right by Creag na Caillich, Beinn nan Eachan, Meall Garbh, Meall nan Tarmachan, Meall Corranaich, Ben Ghlas, and behind it the summit of Ben Lawers. Up to an elevation of about 2000 feet this ridge consists of rocks which belong to the Garnetiferous Schist Zone, while above this, and forming the summit of the ridge, the rocks belong to the Upper Argillaceous Zone. In sailing down Loch Tay we cannot help being struck with the totally different aspect of the mountains upon its northern side compared with those upon its southern side. On the former the mountains rise into a series of rugged corries, while on the latter they present unusually smooth and undulating outlines. There cannot be any doubt that this striking contrast is due to the fact that the mountains on the north side of Loch Tay are capped with a continuous belt of Ben Lawers phyllites, which is absent on those along the south side of the loch. A wide outcrop of the Loch Tay Limestone runs along the base of the Ben Lawers ridge. It can easily be traced, as its course is marked by green

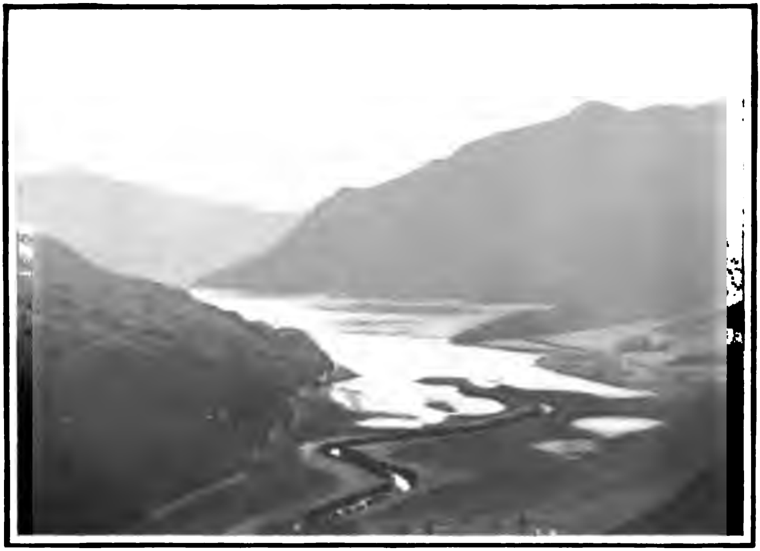

FIG. 95.—View of Loch Lubnaig, from Beinn an t-Shithein, showing the Delta of the Balvaig in the foreground.

Photo. by A. S. REID, M.A., F.G.S.

grassy slopes, through which there occasionally projects an exposure of the limestone.

The hornblende-schists and epidiorites as a rule present more rocky exposures than the clastic schists, and often give rise to prominent features in the landscape, so that they can be distinguished at considerable distances. Examples of the scenic features of the hornblende-schists and epidiorites can be seen almost everywhere in the Southern Grampians. The sill that accompanies the Loch Tay Limestone can usually be recognized at once from the manner in which it projects above the softer and more easily eroded limestone. In the neighbourhood of Strathyre, sills of epidiorite make prominent features in association with the Ben Ledi grits of that district. To the north of Dunoon, on the Firth of Clyde, a sill of epidiorite runs up the side of Hafton Hill, crosses the south end of Loch Loskin, and then continues up the side of Tom Odhar. This sill forms a fir-clad ridge, which makes a prominent feature in the landscape.

In the region occupied by the Central Highland Quartzites and Moine Schists the mountains occasionally present a well-shaped conical outline. This is specially well seen in Schichallion, when viewed from the north-west (see Fig. 96), and Ben Doireann when seen from the south (see Fig. 50, vol. i.).

The numerous lateral faults, which we have already described, often give rise to important features in the landscape, either by bringing together rocks of different degrees of hardness, or by the production of crush rock, which is more easily eroded than the unaltered rock. Reference has already been made to the fact that Glen Ample and Glen Beich lie upon the line of the great Loch Tay fault, which at the west end of Loch Earn brings the Ben Ledi grits against the Loch Tay Limestone and garnetiferous schists (see Fig. 95). Another important fault of the same type crosses Glen Lochay above the falls. The effect of this fault has been to bring the beds on the north side of the great axial line of folding into line with those on its south side, and has given rise to the scenery which characterises this part of Glen Lochay.

When a hillside slopes with the foliation, it will be found that, as a rule, it is smooth and undulating. But when it slopes in an opposite direction, its sides are usually rugged and craggy.

The boundary line between the Highland schists and the Old Red Sandstone of Strathmore is, of course, the great outstanding scenic feature of the region under notice, and has been so often referred to as scarcely to require further description. Fig. 63, vol. i. shows the Menteith Hills from the west of Aberfoyle. The dip in the middle of the ridge indicates the position of the boundary fault. To the left of this dip the hills consist of the crystalline schists of the Highlands, while those to the right are formed of the basal conglomerates of Old Red Sandstone age. When seen from a distance the thick beds of conglomerate which form the Menteith Hills can be distinctly seen to slope away towards the S.E. from the boundary fault, and an observer can take in at a single glance the relationships which exist between the scenery and the geological structure of the ground (see Figs. 56 and 63, vol. i.).

The scenery of the Ochils and Sidlaws presents a low chain of long, round-backed swelling hills, covered

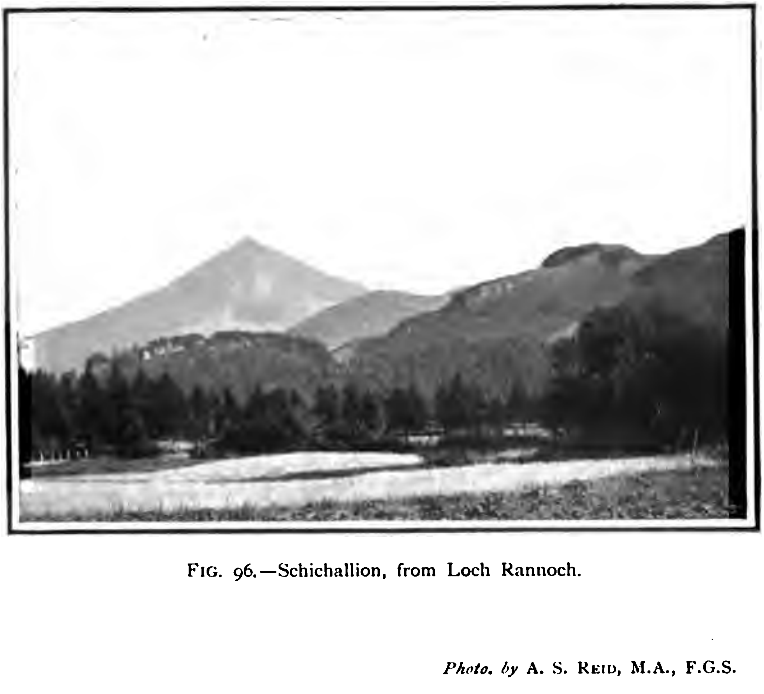

FIG. 96.—Schichallion, from Loch Rannoch.

Photo. by A. S. REID, M.A., F.G.S.

with vegetation, and in some cases under cultivation up to their summits. Defiles or passes intersect the chain, cutting it up into smaller masses and single hills. A reference to Fig. 35 will enable the reader to understand the manner in which the geological structure of the Ochils and Sidlaws has influenced their scenic aspect. It has been shown in Chapter XI. that these hills consist of thick accumulations of lava beds, which have been bent into an anticlinal arch. On the north-west side of this arch the lava beds slope away gently towards the north-west, and often present bold escarpments, which look towards the south-east. This characteristic feature is well seen in Fig. 29, which shows Dunsinane Hill, Perthshire. This hill lies on the north-west side of the anticline, and the succession of lava flows, with their long dip-slopes and steep escarpments, is well shown in the photograph. Fig. 28 shows the cliffs of Kinnoull Hill, with the mural escarpment of lava beds facing the south-east.

It has already been pointed out that some of the dykes of dolerite which intersect the region under notice are probably of Miocene age, and they afford us striking evidence of the vast amount of denudation which has taken place since that comparatively recent period in geological time. Many of these basalt dykes are seen to cross from one end of the region to the other, passing down into the deepest valleys and rising to the summits of the highest mountains, without the slightest indication of ever having formed any lava flows in the bottoms of the deepest valleys. Had the valleys been in existence when the molten lava was intruded into the rocks of which they are formed, it seems most likely that it would have flowed out from the fissures and down the glens. But no evidence of this ever having happened has as yet been found. We are, then, led to the startling conclusion that the erosion of the valley systems of the Highlands has taken place since Miocene times. The basalt dykes often form prominent features in the landscape. In some cases, owing to their superior hardness, they stand up in wall-like masses, when they have frequently been taken for artificial structures (see Figs. 44 and 45). Other dykes weather more rapidly than the surrounding rocks, in which cases they form hollows, often with wall-like sides. Where a dyke crosses a stream or river it is sometimes seen to deflect the stream from its former course, so that it runs parallel with the joints of the dyke. The Linn of Campsie, on the Tay above Stanley, is due to the occurrence of a thick basalt dyke which crosses the river at this point, it having been intruded into the Old Red Sandstone of Strathmore (see Fig. 41).

Between the Carboniferous strata of the valley of the Earn, and the boulder-clay which covers to such a large extent the lowland part of the country, there is a vast period of geological time which remains wholly unrepresented in the area under notice. It is quite possible that some of the Secondary formations may have swept over what is now the Highlands of Scotland, but of this we have no positive evidence.

The evidence which bears upon the glaciation of the country shows that during the period of maximum cold, it must have been buried beneath a continuous sheet of ice, whose movement was to a considerable extent independent of the present valley systems. All over the Highlands and Strathmore, wherever surfaces

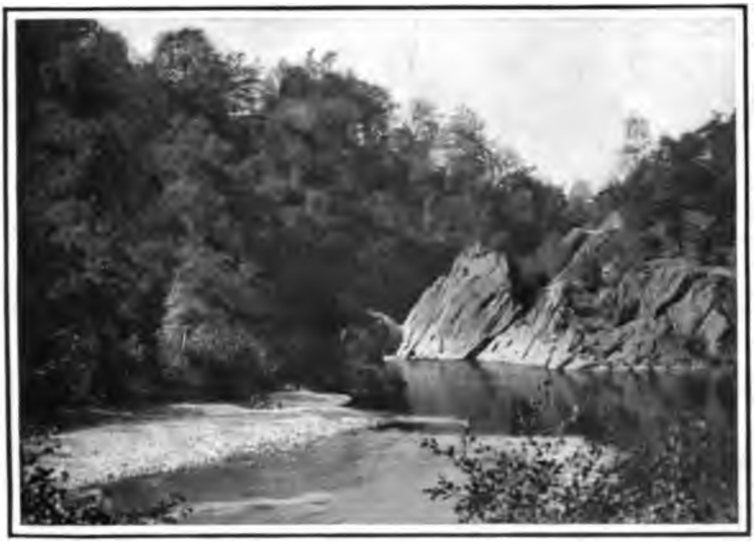

FIG. 97.—The Soldier's Leap, Killiecrankie.

Photo. by A. S. REID, M.A., F.G.S.

of rock are exposed, they are found to be rounded and smoothed in a remarkable manner. A still closer inspection will show that they are often marked with fine straight lines, accompanied by deeper grooves, over wide areas. These lines have the same compass bearings, thus indicating that the great sheet of ice in which the country was enveloped, must have passed over the hills and valleys in a definite direction.

During this period of maximum cold, when the Ice Age was at its climax, the ice-shed lay towards the north-west margin of the Tay basin, and stretched from the mountains north of Rannoch Moor eastwards by Ben Alder to the watershed between the Garry and the Spey. The peaks of many of the mountains within the Highland border show evidence of having been glaciated to their very summits, and striae have been found on the lofty watershed between Glen Lyon and Glen Lochay, at elevations varying from 2000 to 3000 feet, with a trend towards the S.E. On the ridge north of Loch Tay striae have been observed on Creag na Caillich at an altitude of 2250 feet, and further west, near Ben Lawers, at 2000 feet, where they point to the S.E., while Ben Vrackie, north of Pitlochry, rising to an elevation of 2757 feet, has been glaciated to its very summit.

Along the margin of the Highlands the general trend of the ice-sheet was from N.W. to S.E., with some local variations. Upon reaching the lower ground it veered somewhat to the east, and after having traversed the plain of Strathmore, it overrode the Sidlaws and Ochils, when the direction was again changed to a little north of east.

The boulder-clay, which overlies the striated rock-surfaces, is invariably to be met with in favourable situations. The character of this deposit has already been described, and need not again be referred to. Sufficient be it again to point out that all the phenomena connected with this period of the Ice Age, such as the regular and persistent striations upon the rocks, the distribution of boulders which have travelled long distances from their original source, and the manner in which the nearer and more distant kinds of rocks are associated together in the boulder-clay, indicate that for long ages our country must have been buried beneath a sheet of land-ice, just as Greenland is at the present day.

With the gradual amelioration of the climate, the great ice-sheet passed away, and only local glaciers filled the Highland glens. The former existence of these in Perthshire is made abundantly clear by the many fine examples of moraines to be met with in the Highland glens. Perhaps the finest group to be found in the shire is that situated at the head of Glen Garry. Others can be seen in the Dochart valley, from Killin to Tyndrum, and on the banks of Loch Katrine, between Stronachlachar and Loch Lomond.

Everywhere this long period of glaciation has stamped with more or less distinctness its influence upon the physical features of the country. Before the advent of the Ice Age, there must have been a vast accumulation of débris lying upon the surface of the country. For unnumbered ages the action of rain and frost had been breaking up the solid rocks. The whole of the vast accumulation of loose material would have been swept onward upon the first appearance of the great ice-sheet. In the course of time the solid rocks

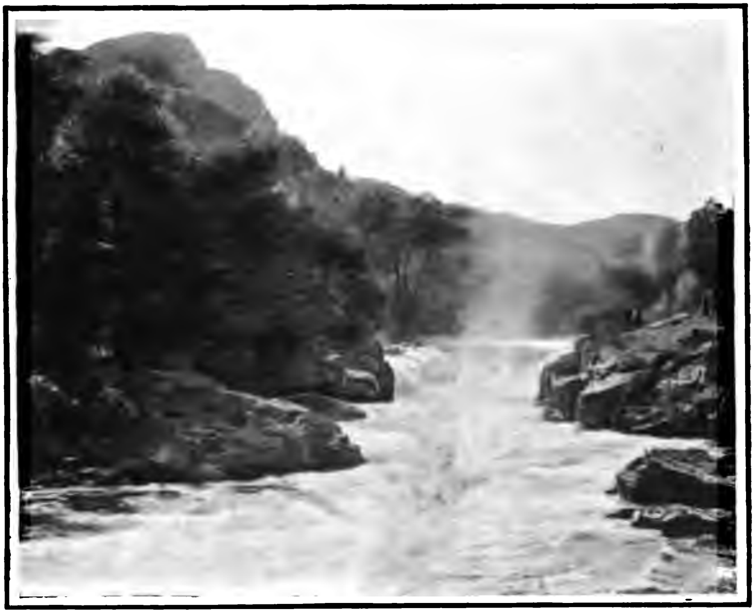

FIG. 98.—The Falls of Tummel, Pitlochry.

Photo. by JOHN STUART.

became bared, and were subjected to abrasion and grinding by the ice. One important topographical feature, which we owe to the action of the ice-sheet, is the great fresh-water lakes, which play such a distinctive part in the scenery of Perthshire. As we have already seen, there is abundant evidence to show that these great rock basins have been excavated out of the solid rock by the grinding power of the ice. A fine example of these is shown in Loch Tummel (see Fig. 84).

If we stand on one of the hills that rise behind the town of Greenock, and allow our eyes to wander over the extensive and grand view of the Firth of Clyde and the distant Grampians that stretch before us, and if at the same time we recall how the existing scenery has been gradually developed out of that of the past, what a wonderful history it presents to us! With the aid of the mental eye landscapes of the most diverse character are seen to blend and dissolve into each other in regular succession; and as one fades away into the dim and distant past, we can perceive through its disappearing lineaments a new and totally different picture being evolved. In this manner, and by the aid of the scientific imagination, we can bring before our mind's eye mountains and valleys, oceans and rivers, glaciers and volcanoes, that have long since passed away.

Looking as far back into geological time as the evidence will carry us, we see that before the Grampian Mountains had been called into being the whole of Scotland must have been buried beneath the waves of a primeval ocean that stretched as far as the eye could reach. Doubtless this ancient sea would be tenanted by strange forms of life, though all traces of these have now been destroyed. The sediments of which the Grampians have been built clearly show that in these remote ages the order of the world must have been much the same as it is at present. On a distant shore the sea would be breaking upon some ancient continent, and the subaerial and marine agents of change would be at work in much the same fashion as they are at the present day. Along this vanished shore line the materials out of which the Grampians were to be built were slowly being accumulated. At one period these would consist of pure white sand or gravel, at another dark ooze-like mud would be accumulated, while during a third period, and in the deeper parts of the ocean, the limy skeletons of microscopic animals sank to the bottom and gradually formed the thick beds of limestone now found amongst the Highland schists.

Let us now suppose that a vast cycle of geological time has elapsed. Look again, and you will see that out of this shoreless ocean there has arisen a great chain of lofty mountains, having a general north-east and south-west trend. The flanks of the mountains slope downwards into a shallow sea, whose shore line can be traced eastwards and westwards till it appears to melt into the distant horizon. Along the base of these mountains this Old Red Sandstone sea is breaking in angry waves upon an iron-girt coast. Let us, in imagination, land upon this ancient coast line, and the first objects that arrest our attention are the rocks of which it is formed. They are the same gnarled and contorted schists as we see in the Grampians at the present day, and even in that remote period of geological time they appear as hoary with age as they do at the present moment. Life is present

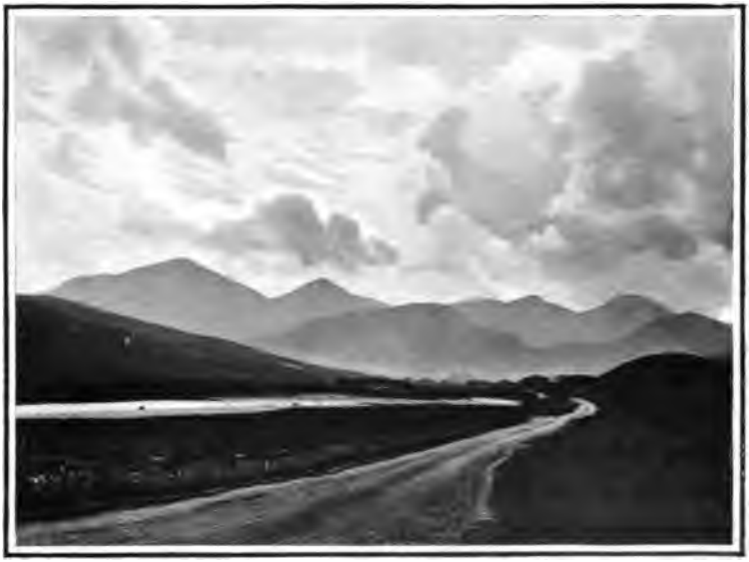

FIG. 99.—Ben More, Stobinian, Stob Garbh, and Cruach Ardran, from Strathfillan.

Photo. by J. W. REOCH.

in the sea, and if we look into some of the rock pools we shall see huge crustaceans crawling about amongst the tangle of sea-weeds, while in the deeper waters swim spined and mail-clad fishes of the most grotesque types. The land surface is covered by a scanty vegetation, consisting principally of plants allied to the recent genus *Psilotum*. Here and there, from above the level of the sea, rise a number of conical hills, down whose sides flow streams of molten lava, which spread across the floor of the sea. Now and again showers of dust and ashes are blown into the air, and fall upon the sides of the volcano or into the sea beyond. After the lapse of long ages the volcanoes become dormant, and the beds of lava are buried deep below the surface of the ocean.

Slowly, and through long ages, the Old Red Sandstone landscape is seen to dissolve and pass into that of the Carboniferous period, of which we just catch a passing glimpse. The land is now seen to be clothed with a luxuriant vegetation, and at first sight it may be difficult to recognize in its gigantic trees any relationship to the dwarfed forms that represent them at the present day. Air-breathers haunt this ancient forest in the shape of insects and scorpions, while the sea is tenanted by a wholly different group of animals from those which existed during the earlier Old Red Sandstone period.

At this point there is a great break or hiatus in the record, and when we look again we find that we are much nearer to our own period. The outlines of the Grampians and the Firth of Clyde appear much the same as they do at the present day. It is impossible, however, to discern the details of the landscape, because the whole region is swathed in a vast sheet of ice over 3000 feet in thickness, which fills the whole of the Firth of Clyde and passes slowly outwards towards the Atlantic Ocean. Here and there the summits of the loftier Grampians emerge like islands from this great sea of ice. But, as we look, this great ice-sheet slowly melts away, till only a few isolated glaciers crawl down the Highland glens, like huge serpents, leaving behind them, to mark their former existence, a trail of morainic débris.

Eventually we come to a period which brings us to the confines of the geologic with the historic, or, to be more accurate, the pre-historic. Glaciers still linger in the higher parts of the Highland glens. The Firth of Clyde, and the valleys that enter it, have now become arms of the sea. The land, however, stands at a lower level, and the estuary reaches much farther inland and up the valleys than it does at present. Rude canoes hollowed out of the trunks of trees ply about the estuary, manned by savage men, in watch for the herds of cattle or deer that inhabit the copsewood and forests which fringe the edges of the Firth. Again the spectacle resumes its forward march, bringing us up to the present time. The glaciers have disappeared, and the land has risen to its present elevation. The rude huts of the savages are supplanted by elegant buildings, diversified by the thriving plantations which adorn the hillsides. Here and there villages and towns have sprung up along the seaboard. The primitive canoes have been replaced by the great ships which are continually passing up and down the channel.

We must not, however, look upon the present scene as if it were a finished piece of work. We saw at the outset of this book that the rocks had nothing to tell us as to the beginning of the present order of things, nor do they enable us to prophesy anything as to their end. There may be as much time in front of us as there is behind us, and Nature's command is ever the same.

> "Yet whirl the glowing wheels once more,
> And mix the bowl again;
> Seethe, Fate! the ancient elements,
> Heat, cold, wet, dry, and peace, and pain.
>
> No ray is dimmed, no atóm worn,
> My oldest force is good as new,
> And the fresh rose on yonder thorn
> Gives back the bending heavens in dew."

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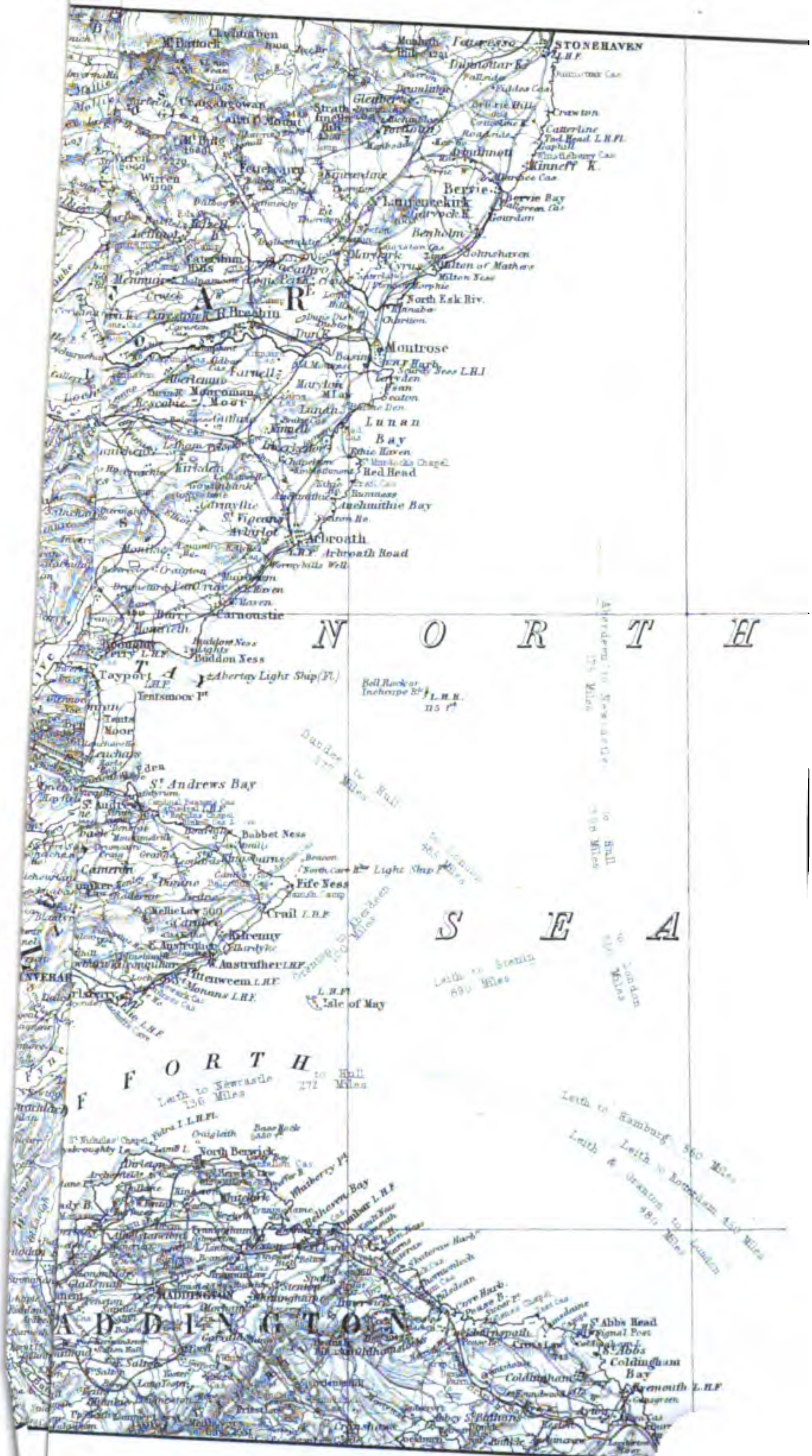

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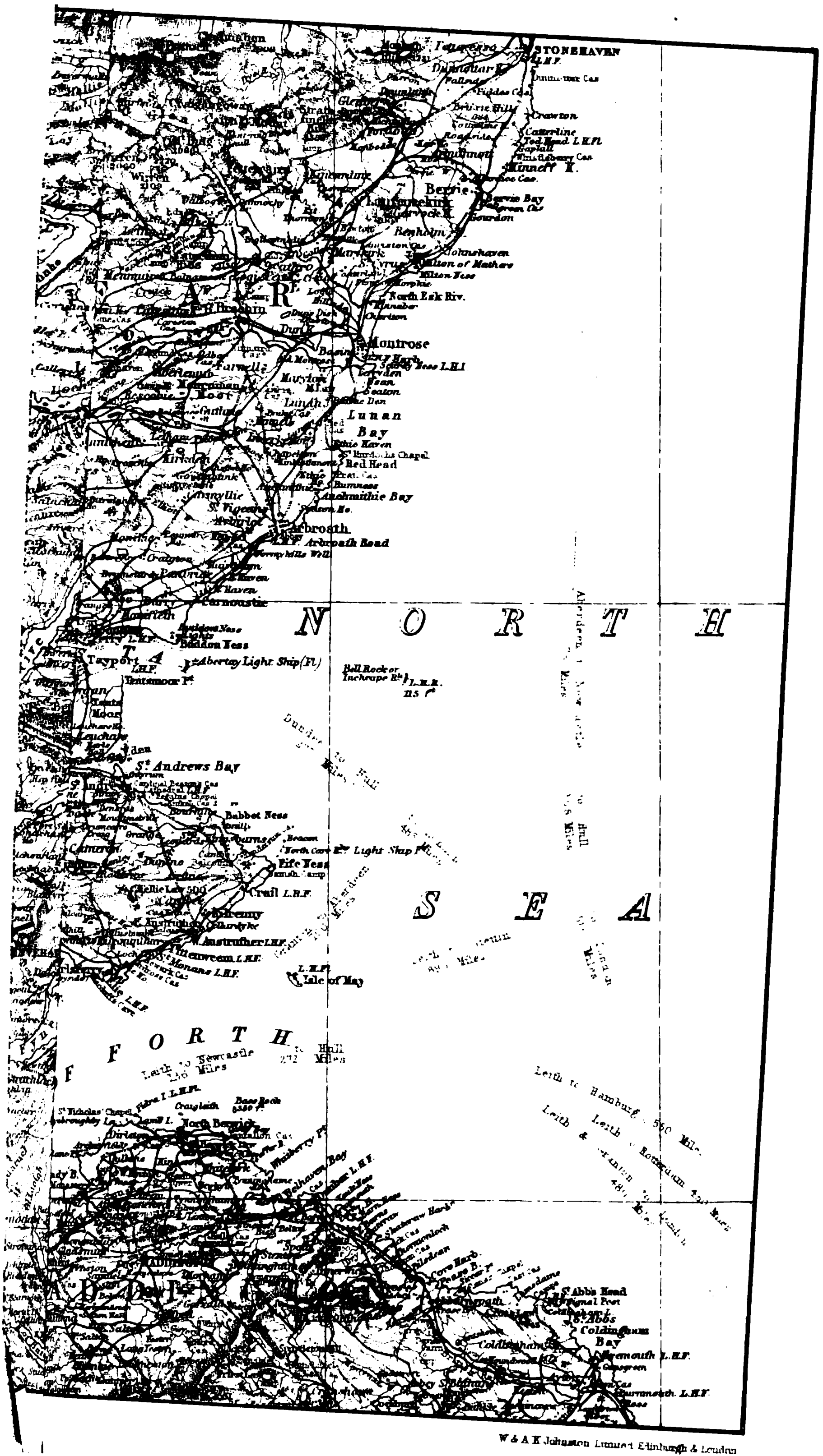

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